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DEMONSTRATION OF ADAPTIVE RANDOM REPORTING GOES DATA COLLECTION--ETC(U)

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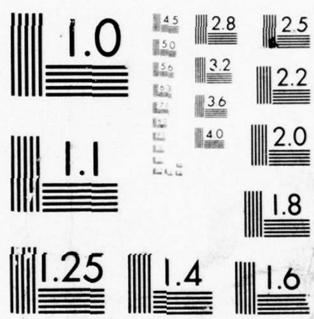

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

New England Division has demonstrated a random reporting capability for collecting data using a standard 1500Hz channel on NOAA's GOES satellite. The new mode has several advantages over scheduled or interrogation modes used to collect hydrometeorologic data required in reservoir regulation in New England. In the random reporting system, hundreds of data collection platforms transmit on a single channel at proper (random) time intervals to insure an acceptable probability of reception. Several techniques have been incorporated to improve reception probabilities, the main ones being a short message (less than 2 seconds),

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and an adaptive algorithm programmed into each platform. This algorithm assures sufficient transmissions during critical times, yet relieves the system of superfluous messages during normal periods when no new or important information has been generated. The demonstration has confirmed that, even without the adaptive feature, at least 200 platforms will report successfully (with 90% probability) within an hour; and the research has revealed future enhancements which could increase the number of platforms by an order of magnitude. A new platform designed around readily available components is now operable and is expected to bring costs within reach of many users.

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Sutron Report No. SCR-333-78-006

FINAL REPORT

NED CORPS OF ENGINEERS

DEMONSTRATION OF ADAPTIVE RANDOM REPORTING GOES DATA COLLECTION SYSTEM

January 15, 1979

Prepared for:

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CONTENTS

I. INTRODUCTION

The Sutron Corporation, under contract to the New England Division of the Department of the Army Corps of Engineers, has developed and successfully demonstrated an adaptive random reporting data collection system that uses the National Environmental Satellite Service's Geostationary Operational Environmental Satellites (GOES) Data Collection System (DCS). The Sutron system is designed to collect data from various types of remote sensing instruments and transmit those data to a central receiving site using the GOES DCS as a relay system. With the Sutron system, data are transmitted to the satellite in a random reporting mode, i.e., there is no scheduled time for the platform to report data as in self-timed systems, and no external control is needed to initiate data transmission as in interrogation systems. In the random reporting system each remote platform establishes its own transmission schedule on the basis of a user-developed algorithm called an adaptive transmission rate algorithm, which changes the transmission rate as the platform data changes.

The Sutron system, with its adaptive remote transmitter, has the following advantages over current self-timed and interrogation data collection systems:

- the quantity of data provided from remote sites is controlled by the users' performance specifications;
- system response time is controlled by user performance criteria;
- the size, complexity, reliability, and power consumption of remote site equipment are significantly improved over self-timed or interrogation mode equipment; and
- GOES DCS channel utilization is improved over both self-timed or interrogation mode operation for most hydrometeorological (hydromet) data collection activities.

Sutron successfully demonstrated its adaptive random reporting system during tests for the Corps of Engineers on 6 and 7 December 1978.

II. PROJECT OBJECTIVES

The program to design, develop, and demonstrate an adaptive random reporting system was divided into the following three tasks:

- Sutron was to design an adaptive random reporting system that would have a 90 percent probability of receiving one message an hour from each of 100 remote data collection platforms operating on a single frequency channel. The theory underlying this system was to be developed and tested by computer modeling. The reporting algorithm was to be developed in conjunction with the New England Corps of Engineers hydrologists. (The Sutron/Corps of Engineers contract was modified in October 1978 and the system was required to meet the Corps of Engineers performance objective of 200 data collection platforms operating on a single channel with a 90 percent probability of receiving one message each hour);

- The key element in the Sutron random reporting system is a fast acquisition demodulator to be installed at the Waltham GOES receive site. Testing was to be done at Waltham; and

- Sutron was to design, build, and install four "smart" DCPs using microprocessor technology. These DCPs were to be capable of executing the reporting rate algorithm developed in Task A. These four DCPs are to be used to simulate 200 or more random reporting units operating on a fixed random regime. Sutron was to supply a test set which would setup and test the DCP for operation.

A final report would provide engineering documentation that included sufficient information so that the Corps of Engineers could draft specifications for possible future procurement of equipment supplied under terms of this contract.

III. DESCRIPTION OF ADAPTIVE RANDOM REPORTING

Random reporting is the transmission of sensor data from a remote site without external timing or control. An understanding of random reporting from remote sites requires an understanding of the statistics of transmitting data through a single channel. For such transmission three basic assumptions are made:

- performance can be defined over a finite time (1 hr in this case);
- a single remote unit transmitting at a rate of $\underline{n}$ times per hour is equivalent to 2 remote units transmitting at 1/2 $\underline{n}$ times per hour; and
- the temporal scattering of transmissions is sufficiently random that the laws of probability are applicable.

The details of the development of the equations that describe random reporting performance are given in Appendix A. The equation from which performance is defined is

$$Ps(1) = e^{\frac{-2tM}{T}} \qquad \text{(Eq. 1)}$$

where Ps(1) = the probability of successfully receiving a given transmission,

t = the length of time of a transmission,

M = the number of transmitters operating in the communications channel, and

T = the average length of time between transmission of all transmitters operating in a channel.

A few other basic equations are

$$Pf = 1 - Ps(1), \qquad \text{(Eq. 2)}$$

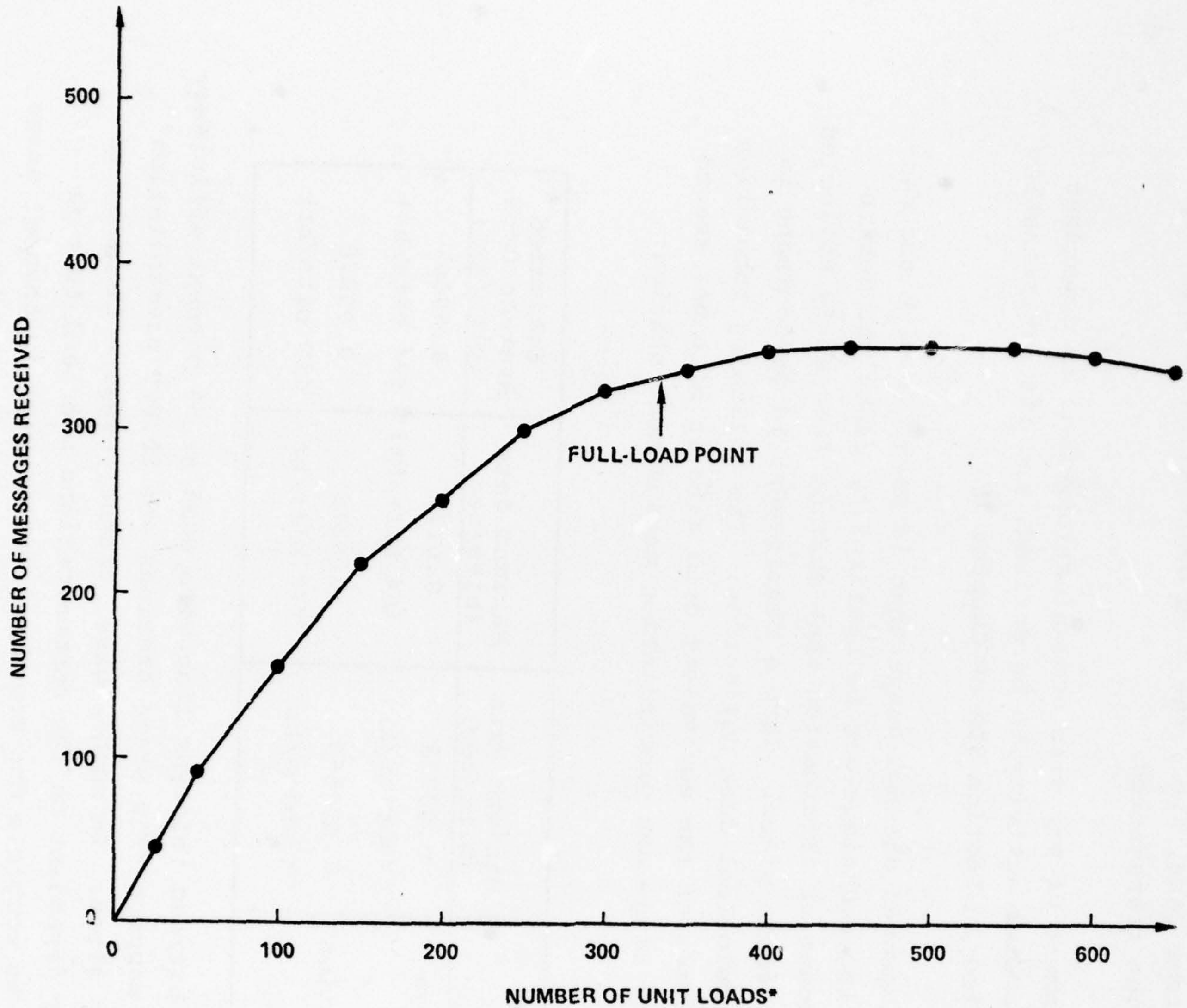
where Pf = the probability of failure of a given single transmission; and

$$Ps(n) = (1 - Pf)^n, \qquad \text{(Eq. 3)}$$

where $Ps(n)$ = the probability of receiving one message in n tries.

Since each remote transmitter can have variable transmission rates that are dependent on parametric activity and algorithm coefficients, a unit communication load is here defined for each remote site as one transmission every 30 min. A fully loaded channel is defined as one in which the average message rate is one message per hour per remote, where that remote is transmitting twice per hour and the probability of successfully receiving three transmissions, Ps(3), is 90 percent.

A single transmission requires a message length of 1.86 sec. (Further discussion on the design of this message is given in Section 4 of Chapter IV.) From these definitions, it is possible to plot the number of received messages per channel as a function of the number of unit loads working into the channel (Figure 1). The full-load point on the curve is the point at which the number of messages received equals the number of unit transmission loads. This number is the average reception of one message per hour per unit load. From this curve, it may also be seen that even if the channel is subjected to much higher loading, it will not result in catastrophic failure. It only means the remote units are "working harder" (i.e., the same or smaller number of transmissions would be received but more transmission attempts would be



*UNIT LOAD = TWO TRANSMISSIONS PER HOUR

FIGURE 1: CHANNEL THROUGHPUT WITH 1.86-SEC MESSAGE

required) to get the same amount of information through the channel. The expanded scale in Figure 2 shows what happens in the extreme case, i.e., the slow degradation of capacity with messages transmitted.

Assignment of per site communications load is dependent on the parameter activity to be defined, and its determination is delineated in Section 3.2 of Chapter IV.

The improved channel usage that is possible with the random reporting technique can be realized by users who desire a small amount of information that must be frequently collected from many remote sites. Such a requirement is predominant in hydrometeorological data collection. The following tabulation is an analyses of the equivalent data rate in bits per second for a river stage and precipitation measurement station:

Parameter	Minimum Rate (bits/sec)	Maximum Rate (bits/sec	Estimated Average Rate (bits/sec)
River Stage	0.00222 (8 bits/hr)	0.0177 (64 bits/hr)	0.00667 (24 bits/hr)
Precipitation	0.000555 (2 bits/hr)	0.0216 (78 bits/hr	0.00278 (10 bits/hr)

If a 110 bit/sec teletype line were used at 50 percent efficiency it would support 8250 stage stations and 20,000 precipitation reporting sites. In such a case, channel usage efficiency is primarily dependent on the communications overhead that is required to complete one message. Improvement in channel usage improvement is compared in two cases with the self-timed reporting in a 1-min time window.

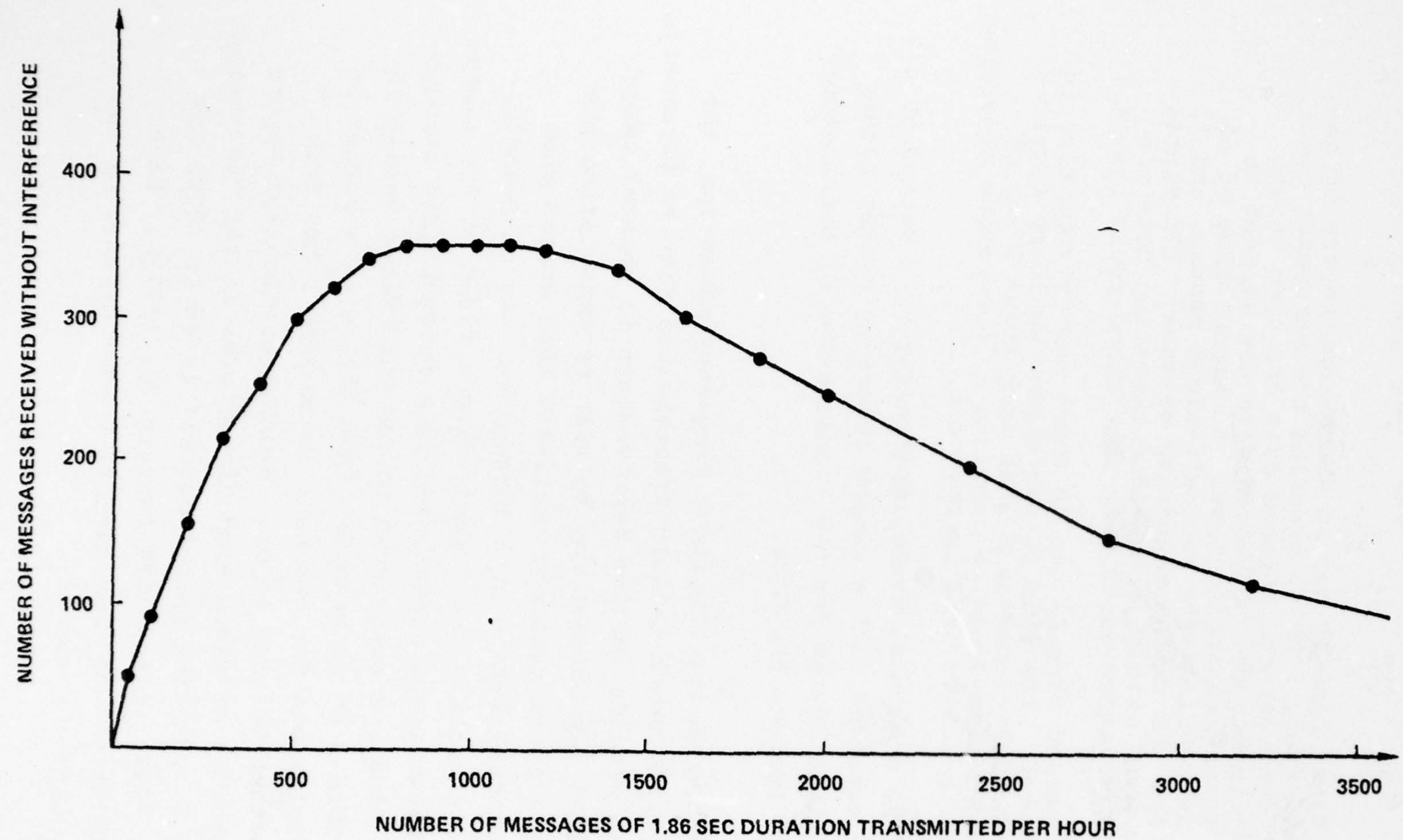


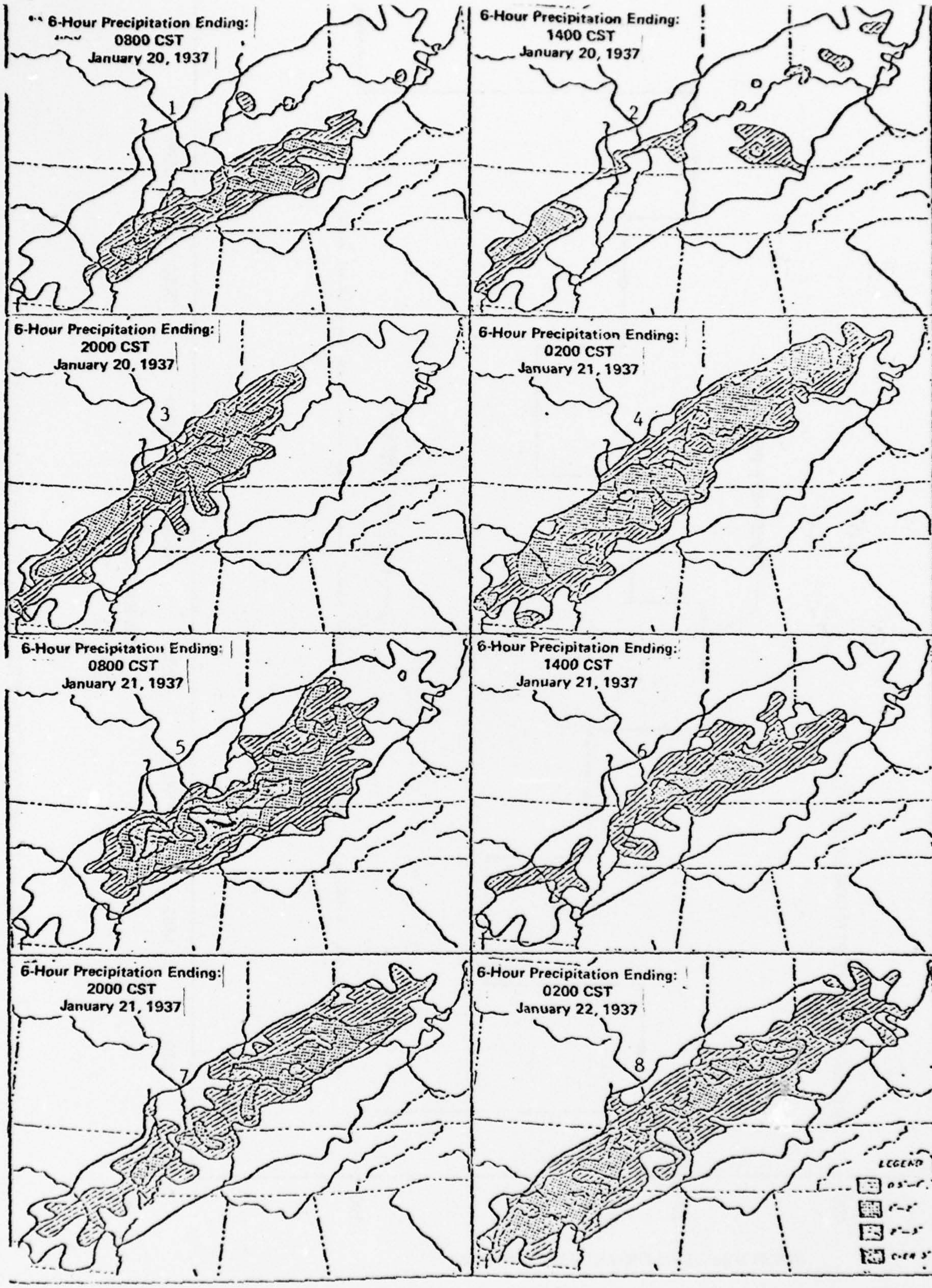
Figure 2. EXPANDED SCALE OF RANDOM REPORTING CHANNEL THROUGHPUT

- The first case is one in which reports are transmitted every 3 hr to describe the parameter over that 3-hr period. Stored data are used in the self-timed mode; no stored data are assumed in the random reporting case. A channel time of 60 sec is required for the self-timed message and 12 sec for the random reporting message. (If stored data were used in the random reporting case comparative improvement over that shown would result.)

- The second case is one in which hourly reporting is required. The same 60-sec window would be required in the self-timed case, but only about 5 sec of channel time would be required in the random reporting mode, a twelve-fold improvement.

Conservatively, a channel usage improvement by a factor of 4 to 10 can be expected with a random reporting system rather than a self-timed system for the transmission of hydrometeorological data through the GOES.

In addition to the reporting frequency advantage, the adaptive feature, which tailors transmission rate to parametric activity, can provide further improvements in channel usage. This additional improvement may be seen by considering the large variability in parameter activity that occurs when reporting rainfall data over a large area. As an example, consider the reporting performance from a field of 500 random reporting transmitters distributed in a uniform grid throughout a storm area. A storm area in the Ohio River valley is shown in Figure 3 as an example. [The figure is a series of eight isohytel plots for six-hour increments taken from National Weather Service Report, Hydrometeorological Report #34, "Meteorology of Flood Producing Storms in the Mississippi River Basin." The time period covered is 48-hr (0200 CST January 20, 1937, to 0200 CST January 22, 1937)]. Each remote transmitter was reporting at a rate defined by the equation in Figure 4 and is



Incremental Isohyetal Patterns
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Figure 3. 1936 OHIO RIVER BASIN RAIN STORM

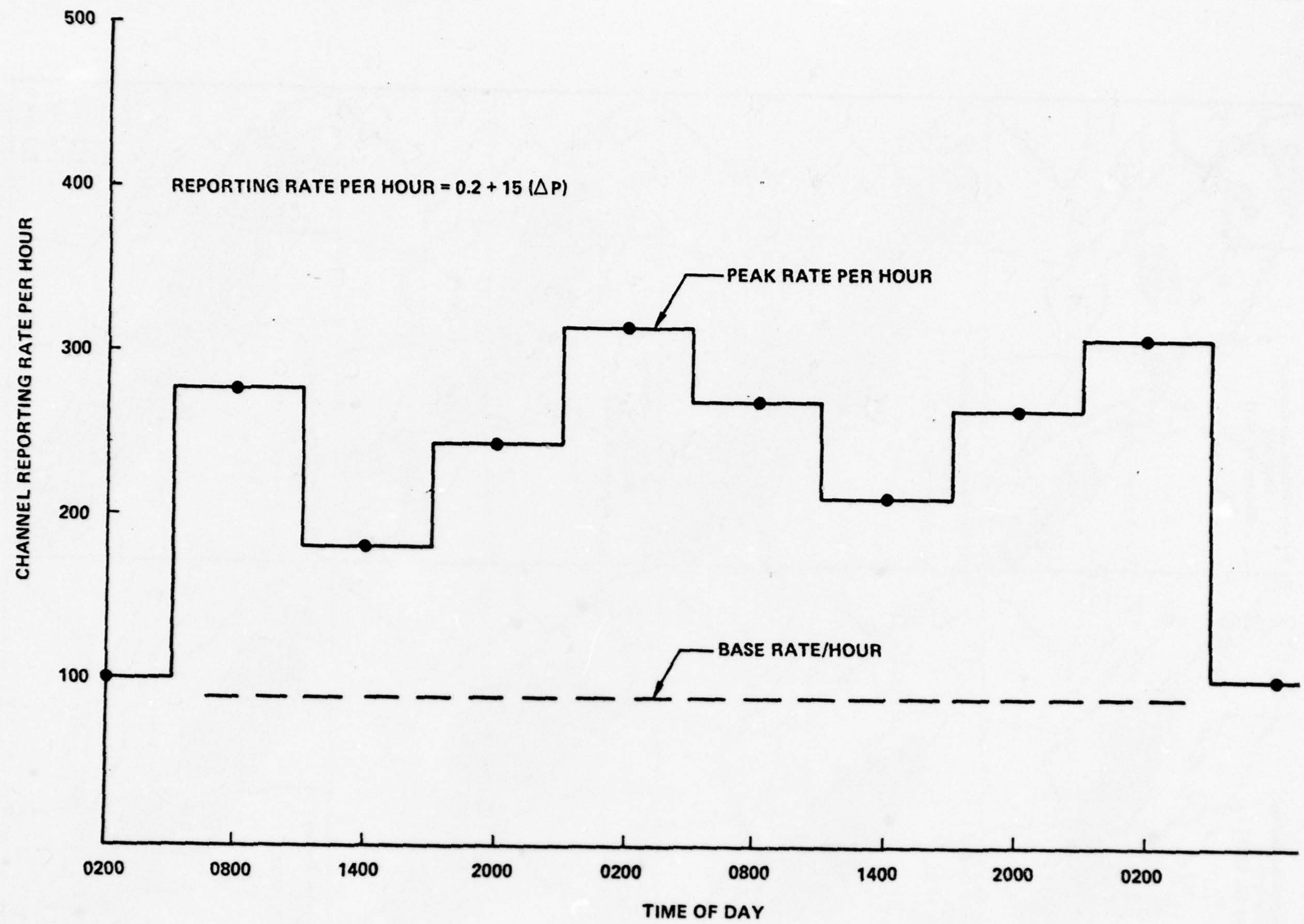


Figure 4. 500-STATION PRECIPITATION PERFORMANCE

$$\text{Transmissions per hour} = 0.2 + 15(\Delta P)$$

where ΔP = incremental accumulated precipitation (in./hr)

The number of hourly transmissions from this field during the 48-hour period is shown in Figure 4. The peak rate is 330 transmissions/hr, which is equivalent to 165 unit loads (Figure 1). About 225 of those 330 transmissions (about 70 percent) would be received.

Individual site performance for a 1 in./hr rate of accumulation is 15.2 reports/hr. Ten of these transmissions would be received, giving a reporting interval of 6 min. In this case, 500 stations were supported by one channel, resulting in one report received for every 0.16 in. of accumulated rainfall.

IV. SYSTEM COMPONENTS

1. SATELLITE

The Geostationary Operational Environmental Satellite (GOES) system is an environmental data collection system operated by the National Oceanic and Atmospheric Administration (NOAA). Three satellites are in synchronous orbit at all times; one each at 75°W, 105°W, and 135°W longitude. The satellite at 105°W is considered a spare. The most familiar product of GOES is the meteorological imagery shown each day on local television newscasts. In addition to the three U.S. satellites, identical satellites are supported by Japan, European nations, and the Soviet Union. These satellites have been operational for about 5 years.

As part of its environmental monitoring capability, NOAA also supports a substantial communication system (Figure 5). Two sets of uplink and downlink frequencies are used, the first at 2034.9 (uplink) and 1694.5 MHz (downlink) for communications between the spacecraft and large receiver systems and the second at 401.8 MHz (uplink) and 468.8 MHz (downlink) is for communications with remote low-power transmitters. The 468.8 MHz downlink is a narrowband command-and-control link that is monitored for unique command words by all remote stations equipped to receive the signal. In addition to command words, a National Bureau of Standards (NBS) time code is also transmitted on this link. The 401.8 MHz uplink capacity is divided into about 250 1.5-KHz-wide channels, which permits low-data-rate, low-power, remote communication. The remote transmitters are characterized by 13- dB to 3- dB antenna gains with transmission power from 5 to 40 w, respectively.

GOES DATA COLLECTION SYSTEM

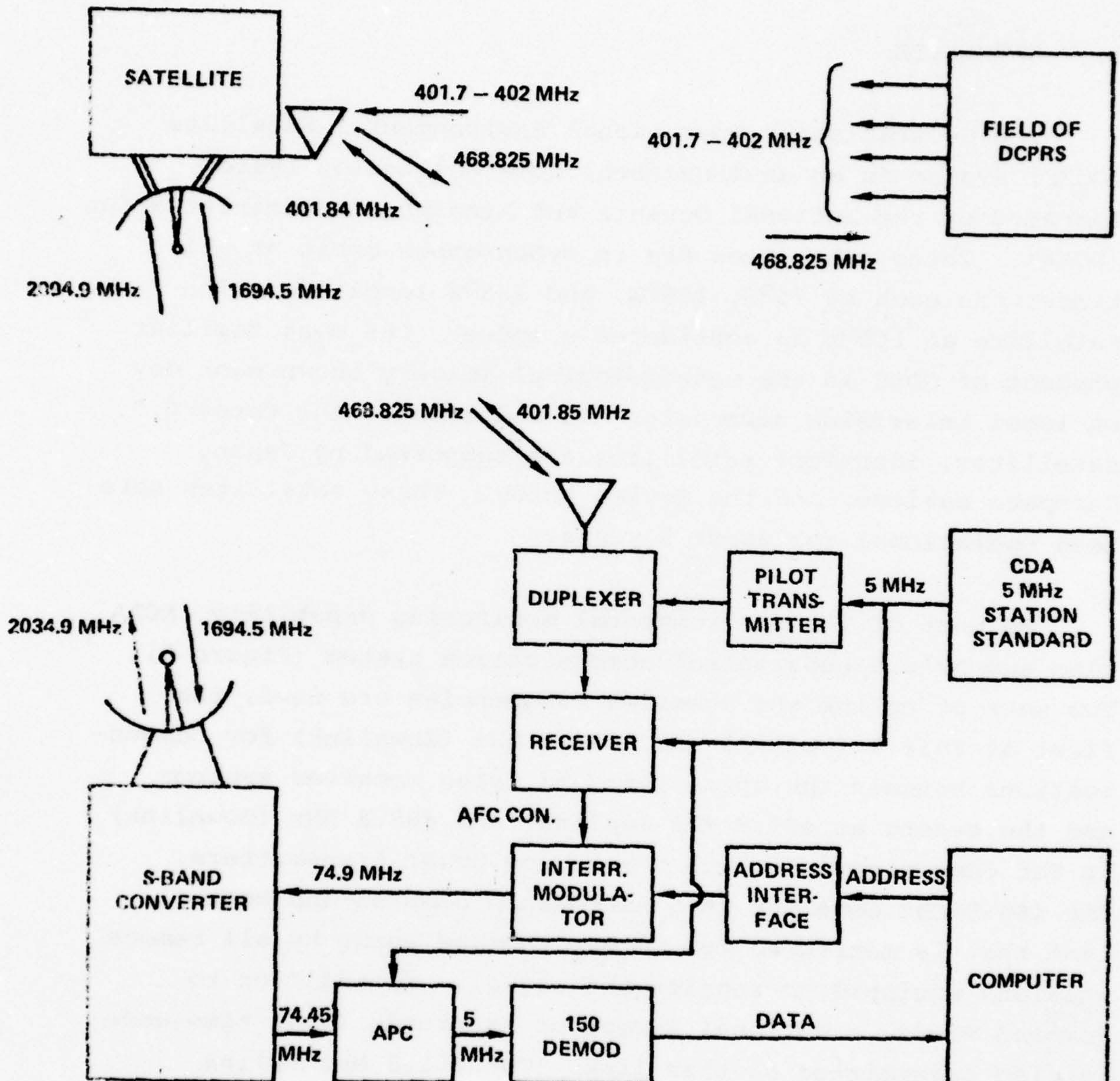


Figure 5. GOES DCS SYSTEM FREQUENCY PLAN

Figure 6 is a block diagram of the total GOES DCS. The major components are

- the satellites;
- command-and-data acquisition system at Wallops Island, Virginia, that includes:
  - five receiving systems using 40- to 60-ft diameter parabolic dish antennas,
  - a redundant disk-supported computer system that acquires and forwards received data to the National Meteorological Center (NMC) (one day of data is backed up at the Wallops computers),
  - triple redundant lines to the NMC,
  - uninterruptable power sources, and
  - a system by which each channel is tested at least once per day using a test transmitter (ten operators are scheduled to maintain the DCS system year round);
- a redundant computer system at NMC that transmits data to users either by leased line or dial-in line (one day of backup data are stored at NMC); and
- users receive sites (not shown in Figure 6), which are equivalent to a small-scale Wallops Island site.

2. RANDOM REPORTING DATA COLLECTION PLATFORM (RR/DCP)

The Sutron RR/DCP is designed to collect data from various types of remote sensing instruments and transmit them using the the Geostationary Operational Environmental Satellite (GOES) data collection system (DCS) to a central receive site. The Sutron RR/DCP reports data in a random reporting mode, meaning that there is no scheduled time for each platform to report. However, each platform bases its own transmission schedule on an algorithm called an adaptive transmission rate algorithm.

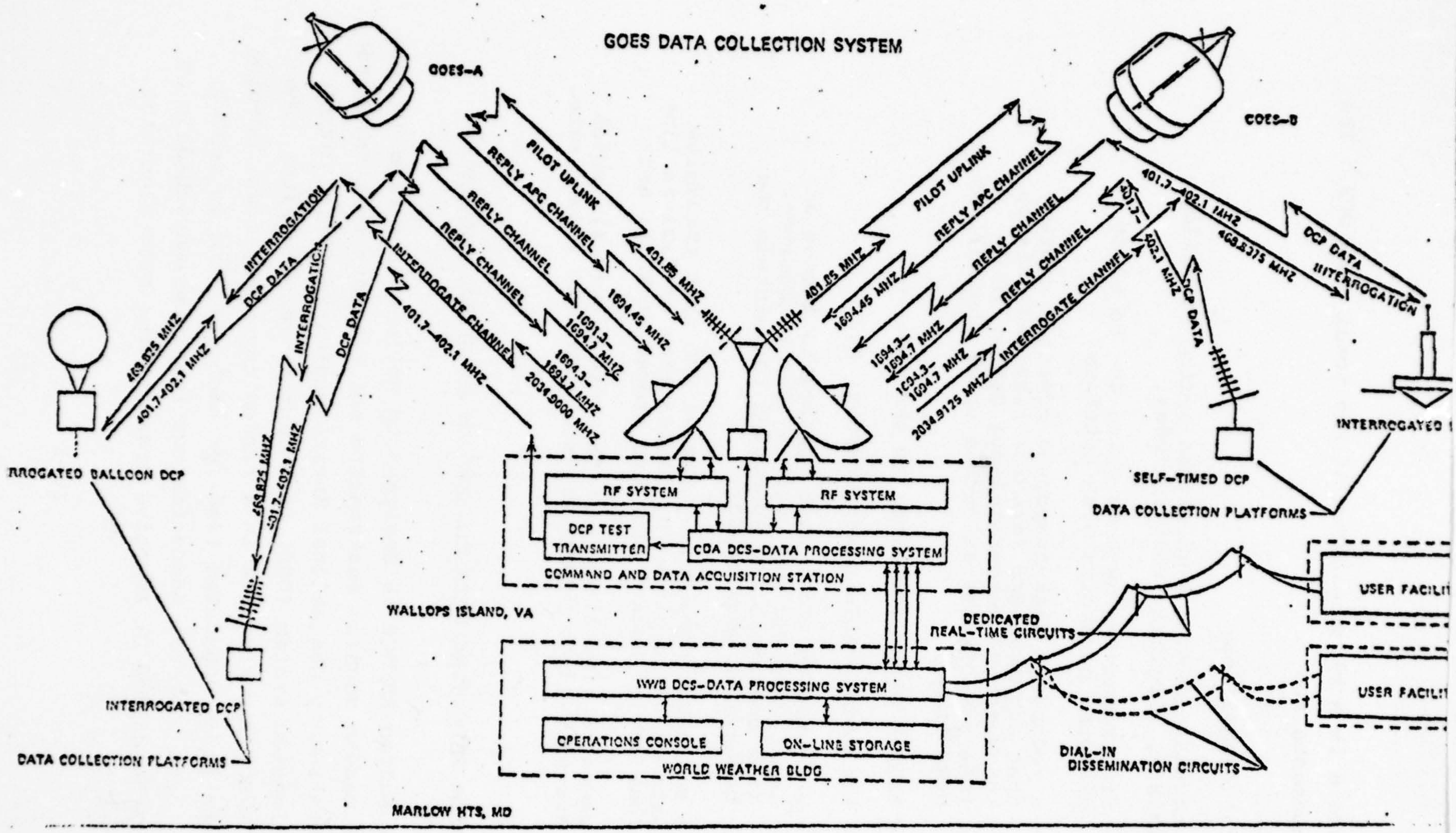


Figure 6. GOES/DCS SYSTEM DESCRIPTION

This algorithm uses constants supplied by the user at setup time and actual platform data to compute a transmission rate that changes as the platform data changes.

The Sutron RR/DCP designed for the Corps of Engineers testing consists of a microprocessor, transmitter, instrumentation interface, microterminal, and power supply. These components are discussed in the following subsections. A listing of RR/DCP features and hardware specifications is given in Tables 1 and 2.

2.1 Microprocessor

The Sutron RR/DCP is a microprocessor-controlled data collection platform. The microprocessor performs the functions of (1) collecting data, (2) formatting data, (3) transmitting data, (4) timing, and (5) adapting the transmission rate to changes in data. These and related RR/DCP functions are executed by an executive program and associated subroutines, which are stored in erasable programmable read-only memory (EPROM).

The RR/DCP is also equipped with the RCA UT-5 operating system ROM, which allows an operator using the microterminal to execute RR/DCP functions separate from the executive program. This capability allows the RR/DCP to be fully exercised and tested. Even new programs may be written and executed without any hardware changes using the UT-5 operating system.

The Sutron RR/DCP uses the RCA 1802 microprocessor with 3.3 kbytes memory to perform its control functions. Appendix D gives flowcharts, memory maps, register assignments, and a machine code listing for all RR/DCP software.

Table 1. RR/DCP FEATURES

• Adaptive reporting rates based on local platform data and user data requirements.
• 36 mw average power consumption.
• Compatibility with random reporting channels.
• Operating system (RCA UT-5) permits wide use of microprocessor to exercise existing programs and write/run new ones.
• Easy set up/testing using a hand held terminal with 8 digit LED display and keyboard.
• A 12-bit analog-to-digital (A/D) converter with an accuracy of ± 0.05 percent of full scale.
• Serial digital interface to instruments such as ''tipping bucket'' rain gauge.
• Operator selection of adaptive reporting parameters: base rate, alert rate, warning rate, alert level threshold, warning level, slope factors.
• Internal backup battery power to random access memory (RAM) to allow off-site set up of platform.
• Fool proof start-up hardware ensures that the platform will operate when left at remote site.

Table 2. HARDWARE SPECIFICATIONS

DIMENSIONS:	Length 10 ½ in. Width 6 in. Height 3½ in.
WEIGHT:	ca 7 lb
CONTROLS:	Microterminal data entry that execute four self-test programs
CONNECTORS:	Power and instrumentation: 12 pins Microterminal : 20 pins
ENCLOSURE:	Environmentally sealed
POWER REQUIREMENTS:	ca 36 mw (assuming two transmissions/hr) and a 10-volt transmitter, 30 watts peak
POWER SUPPLY:	12V lead-acid battery suggested
OPERATING TEMPERATURE:	$-25^{o}C$ to $55^{o}C$ (two-day thermal time constant with 1-in. polyurethane foam container)
TRANSMITTER:	GOES DCS compatible; standard: 10-watt transmitter with 10dB antenna

2.2 Transmitter

The transmitter used by the RR/DCP is a 10-watt GOES DCS compatible transmitter. A 10dB, 401.8 MHz antenna is used with the transmitter. The microprocessor controls the transmitter in order to send a message using the format shown in Table 3.

2.3 Instrumentation Interface

The Sutron RR/DCP is equipped with an analog data interface and a serial digital data interface. The analog interface is designed to convert analog signals to a 12-bit binary word with a conversion accuracy of ± 0.05 percent of full scale. The analog signals must be between 0 and 1 volt. A 1-volt reference (capable of supplying 10 ma) is available for instrumentation. Data are read every 8 min and whenever a transmission is made. Each analog measurement takes about 2 sec.

A serial-digital data interface is provided to accommodate the tipping bucket rain gauge. The serial digital interface causes a counter in memory to be incremented with each pulse on the serial digital data line.

The RR/DCP can accommodate either two analog data inputs or one analog and one serial-digital data input. For the Corps of Engineers demonstration the DCP was limited to two parameters although additional parameters may be accommodated.

Table 3. TRANSMISSION TIMES AND FORMATS

Function	Time (sec)	Format
Carrier	0.50	
Clock	0.48	48 bits 1-0 pattern
MLS	0.15	15 bits
ID	0.31	31 bits (unique platform identifier)
Data	0.32	Byte 1 X1 $B_5B_4B_3B_2B_1B_0$ Bits 0-5 Parameter 2 Byte 2 X1 $B_{11}B_{10}B_9B_8B_7B_6$ Bits 6-11 Parameter 2 Byte 3 X1 $B_5B_4B_3B_2B_1B_0$ Bits 0-5 Parameter 1 Byte 4 X1 $B_{11}B_{10}B_9B_8B_7B_6$ Bits 6-11 Parameter 1 X indicates odd parity
EOT	0.08	8 bits EOT character
TOTAL	1.84	

2.4 Microterminal

The microterminal is the control device used to set up and test the RR/DCP. It is a hand-held terminal with an eight digit LED display and 23 keys. Instructions are entered through the keyboard to run test programs, examine memory, and enter platform constants. The eight-digit display is used to display data and test results. The microterminal is programmed to operate both with hexadecimal (HEX) numbers and with decimal numbers.

2.5 Power Supply

The RR/DCP power supply utilizes a 12-volt battery and delivers a maximum of 0.5 amps at 6.1 volts to the logic section. The RR/DCP power consumption is shown in Table 4. Since the average power consumption is about 36 mw, a 10 amp-hr, 12-volt battery would last 90 days, and a 40 amp-hr, 12-volt battery would last 360 days. Therefore, in most applications no solar panels are required. The power supply has over voltage and reverse voltage protection so that a fuse will blow when output voltage is greater than 7 volts or when power is applied in reverse.

3. INSTALLATION

There are several steps to the installation of the RR/DCP: instrumentation must be selected and interfaced to the platform, values must be selected to control the adaptive transmission rate algorithm and entered into the platform, and the platform should be tested. This section gives details on these steps. A sample setup test sheet is shown in Figure 7.

Table 4. RR/DCP POWER CONSUMPTION

Function	Duty Cycle	Average Consumption	
		Current (ma)	Power (mw)
Data Acquisition	20 ma for 4-sec every 8 min	0.17	2
Transmission twice per hour (1 unit load)	2.0 amp for 1.86-sec every 30 min	2.1	26
Continuous	Microprocessor calculating at slow rate	0.7	8
TOTAL		∿3.0	36

Date: ______________________ Operator: ______________________

Location: ____

HEX ENTRIES – PROCEDURES 1

ADDRESS	CONTENTS	SETUP	DESCRIPTION
8C62			31 Bit ID Code
8C63			"
8C64			"
8C65			"
8C52			00 FDC Precip. 01 Bucket

DECIMAL ENTRIES – PROCEDURES 2

ADDRESS	CONTENTS	SETUP	DESCRIPTION
8C36			Base Transmission Rate x 100 (Trans/hr x 100)
8C38			Alert Transmission Rate x 100 (Trans/hr x 100)
8C3A			Flood Transmission Rate x 100 (Trans/hr x 100)
8C3C			Number 0-100 dependent on stream
8C3E			Precip. Multiplier
8C40			Alert Level x 100 (ft x 100)
8C42			Flood Level x 100 (ft x 100)
8C2C			Current Stage x 100 (ft x 100)
8C32			Current Precip. Level x 100 (in. x 100)

Figure 7. RR/DCP CHECK-OUT SHEET

TESTING/CALIBRATING PROGRAMS

168$P	8C28	____________	Minimum Stage Level
170$P	8C2A	____________	Minimum Precip. Level; If "1" Appears Bucket Is Selected
178$P	8C2C	____________	Current Stage
	8C32	____________	Current Precip.
180$P			Transmits Values at 8C66
158$P	8C46	____________	RF FWD
	8C48	____________	RF REF

Figure 7. RR/DCP CHECK-OUT SHEET (Cont'd)

3.1 Instrumentation

The instrumentation is connected to the RR/DCP through the J5 connector mounted on the side of the DCP enclosure. Pin assignments for J5 are given in Table 5.

A voltage of 0 to 1 volt on Pin E gives an internal reading of 0 to 4000 for Parameter 1; the same voltage on Pin J gives an internal reading of 0-1000 for Parameter 2. The 1-volt reference on Pins F and K is supplied as an interface between the DCP and a variety of sensors.

When the system is used to monitor river stage and precipitation levels, Parameter 1 is best suited for the stage and Parameter 2 is best suited for precipitation. In this configuration, the 0 to 4000 internal range of Parameter 1 corresponds to river stages of 0 to 40.00 ft with a resolution of 0.01 ft. Similarly, the 0-1000 internal range of Parameter 2 corresponds to precipitation of 0 to 10.00 in. with a resolution of 0.01 in.

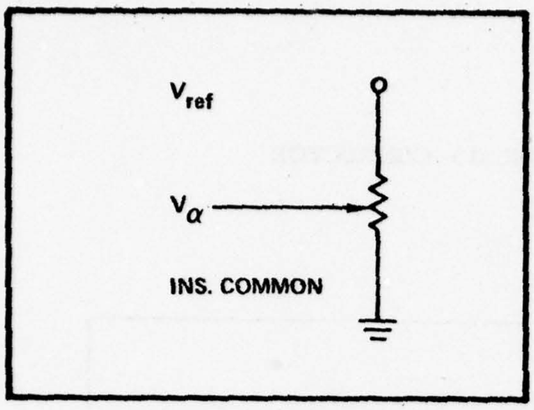
The reference voltage supplied to the output connector is used internally as full-scale reference; therefore, it should also be used as the external instrumentation full-scale reference voltage. All internal measurements are scaled to this reference. Figure 8 shows a typical setup using a potentiometric sensor and one with a YSI linear thermister network.

The serial-digital interface can be used instead of the analog interface for Parameter 2. This interface counts the pulses on Pin D, the tipping bucket line. Figure 9 shows its connection to a tipping bucket rain gauge.

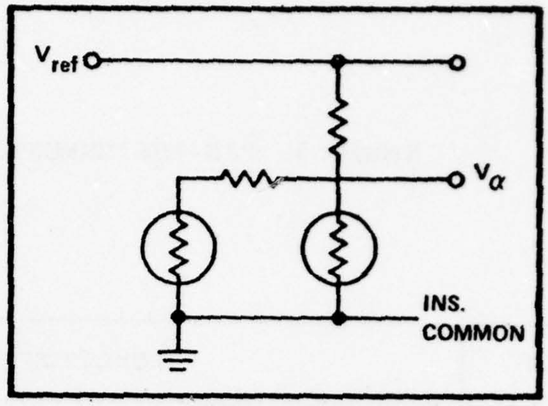
The RR/DCP is designed to calibrate instruments with which it interfaces. Since the position of a potentiometer is

Table 5. PIN ASSIGNMENTS FOR J5 CONNECTOR

PIN	FUNCTION
A	+12 volts - battery (+)
B	no connection
C	power common-battery (-)
D	tipping bucket line
E	$V\alpha$ (0-1 volt) analog input for parameter 1
F	V_{ref} (+1 volt 10ma) instrument reference voltage
H	instrument common
J	V_{β}(0-1 volt) analog input for parameter 2
K	V_{ref} (+1 volt 10ma) instrument reference voltage
L	instrument common
M	no connection
N	no connection



A. POTENTIOMETRIC SENSOR



B. LINEAR THERMISTER NETWORK

Figure 8. TYPICAL INSTRUMENTATION SETUP

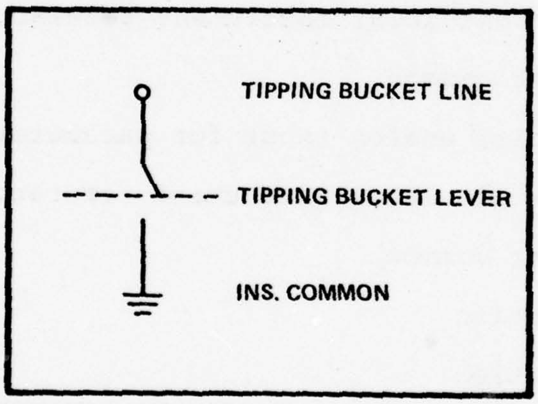


Figure 9. SERIAL-DIGITAL INTERFACE CONNECTION TO TIPPING BUCKET RAIN GUAGE

probably unknown when it is attached to the RR/DCP, calibration becomes necessary. The potentiometer must be aligned so that its full-scale operation corresponds to the full-scale RR/DCP reading range. The RR/DCP assists in this alignment process by accepting an operator input of the current potentiometer value and then computing the minimum real-world value it will read (i.e., the value at V=0). If this value is different from the desired minimum of the instrument, adjustments are necessary. In the case of a stage monitor with float, pully, and wheel, the wheel must be rotated and the test performed again until the minimum value desired is achieved. The actual minimum of the instrument does not need to be zero.

In the case of non-zero minimum, the RR/DCP will continue to transmit its reading ranging from 0-4000 and 0-1000, but the minimum value must be added to the transmitted value to determine the actual level. For example, if the minimum were 50 (00.50 ft) and the transmitted value were 1000 (10.00 ft), the actual stage would be 1050 (10.50 ft).

3.2 Rate Selection

The operator controls the adaptive transmission rate algorithms by selecting values to enter at set up time. Values are required at set-up time for the base transmission rate, alert transmission rate, warning transmission rate, alert level, warning level, and slope factors. The rate at which data are transmitted depends on the values for these rates and levels and the measurements the RR/DCP makes of its instrumentation. The following discussion presents the procedures used to select values for the RR/DCP. A discussion of how to enter the values into the RR/DCP is given in Section 3.3.

Equations 4 and 5 are simplified versions of the transmission rate calculation equations.

$$\text{Rate } 1 = R_i + A|\Delta\alpha| \qquad \text{(Eq. 4)}$$

$$i = 1,3$$

$$\text{Rate } 2 = R_1 + B|\Delta\beta| \qquad \text{(Eq. 5)}$$

where Rate 1, Rate 2 = transmission/hr(T/hr) for parameters 1 and 2,

α = parameter 1 (i.e., stages)

β = parameter 2 (i.e., precipitation)

R_1 = base transmission rate (T/hr),

R_2 = alert transmission rate (T/hr),

R_3 = warning transmission rate (T/hr),

A,B = slope factors,

$\Delta\alpha$ = change in α*/hr (based on 16-min sample), and

$\Delta\beta$ = change in β*/hr (based on 8-min sample).

*Hourly change in alpha and beta.

and

$R_i = R_1$ if α is below the alert level

$R_i = R_2$ if α is below the warning level

$R_i = R_3$ if α is above the warning level

Figure 10 illustrates the rate calculations of the DCP in instances in which the river stage is Parameter 1. The three curves correspond to α being below the alert level, α being below the warning level and α being at or above the

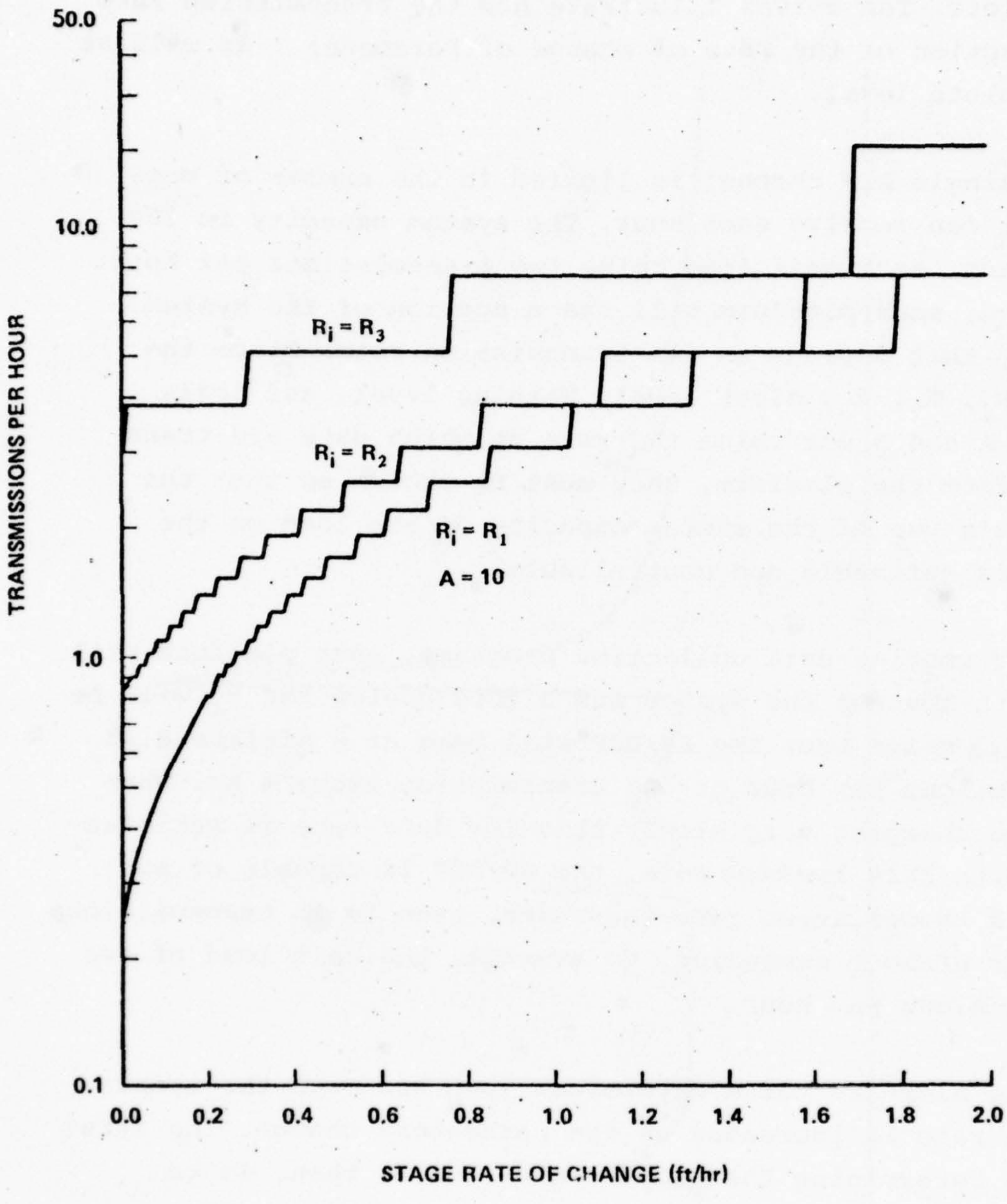


Figure 10. TRANSMISSION RATE ADAPTS TO PARAMETER VARIATIONS

warning level. Slope Factor A is the same in each of the three plots. The curves illustrate how the transmission rate is a function of the rate of change of Parameter 1 as well as its absolute level.

A single DCS channel is limited in the number of messages it can receive each hour. The system capacity is 300 unit loads, each unit load being two transmissions per hour. Therefore, each platform will use a portion of the system capacity that depends on its transmission rate. Since the values R_1, R_2, R_3, Alert level, Warning level, and Scale Factors A and B determine the rate at which data are transmitted from the platform, they must be chosen so that the platform's use of the system capacity or the load on the system is definable and controllable.

For routine data collection programs, each platform will be a unit load on the system and a good choice for R_1 will be .25, which means that the RR/DCP will make at a minimum 0.25 transmissions per hour or one transmission every 4 hr. When data are changing very slowly this low data rate is satisfactory. With this low base rate, the RR/DCP is capable of substantial transmission rate increases, even to 15 transmissions per hour without exceeding, on average, the unit load of two transmissions per hour.

The Slope Factor A determines just how much the transmission rate is increased as the parameters change. The first step in determining the proper value for A, then, is to estimate the expected hourly variation for the parameter. This value can be a estimated or calculated. Hydrographs, such as those shown in Figure 11, can be used in the estimation.

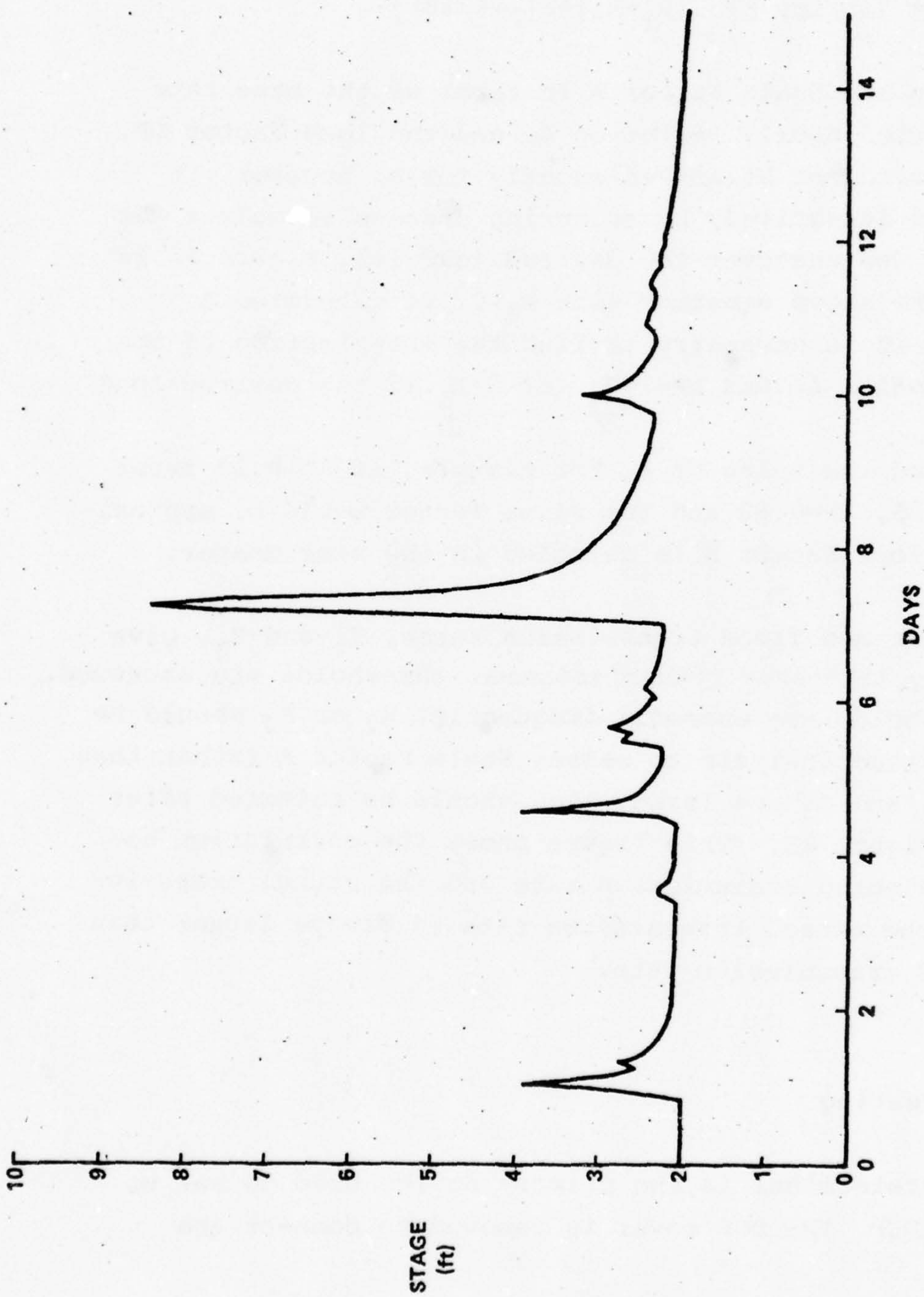


Figure 11. SAMPLE CALCULATION OF $\overline{\Delta\alpha}$

Scale factor can then be determined either algebraically or graphically. The equation for the algebraic method is

$$LF = 7.5/\mathrm{int}\left[15/(R_1+A\cdot|\Delta\alpha|\cdot 16/60)\right] ,$$

which defines the Scale Factor A in terms of the base rate R_1, the expected hourly variation $\Delta\alpha$ and the load factor LF. This equation cannot be solved exactly for A; however, it can be solved iteratively by selecting successive values for A until LF=1 (or whatever the desired load is). Figure 12 is a graph of the above equation with $R_1=0$. To determine A graphically, it is necessary to find the intersection of the lines that define $\Delta\alpha$ and $LF=1-\frac{R_1}{2}$ (or $2-\frac{R_1}{2}$ if the desired load is 2) and read the value of A. For example, if $\Delta\alpha=0.20$ ft/hr and R_1 is 0.25, LF=0.88 and the slope factor would be approximately 34. Slope Factor B is selected in the same manner.

The alert and flood transmission rates, R_2 and R_3, give substantially increased transmissions as thresholds are exceeded. If the thresholds are exceeded frequently, R_2 or R_3 should be used in the load analysis to select Scale Factor A rather than R_1. When R_2 and R_3 are large, they should be selected after consulting Figure 13. This figure shows the correlation between the selected transmission rate and the actual transmission rate; the actual transmission rate is always larger than the selected transmission rate.

3.3 Set Up Testing

The microterminal is the primary device used to set up and test RR/DCP. The DCP cover is removed to connect the

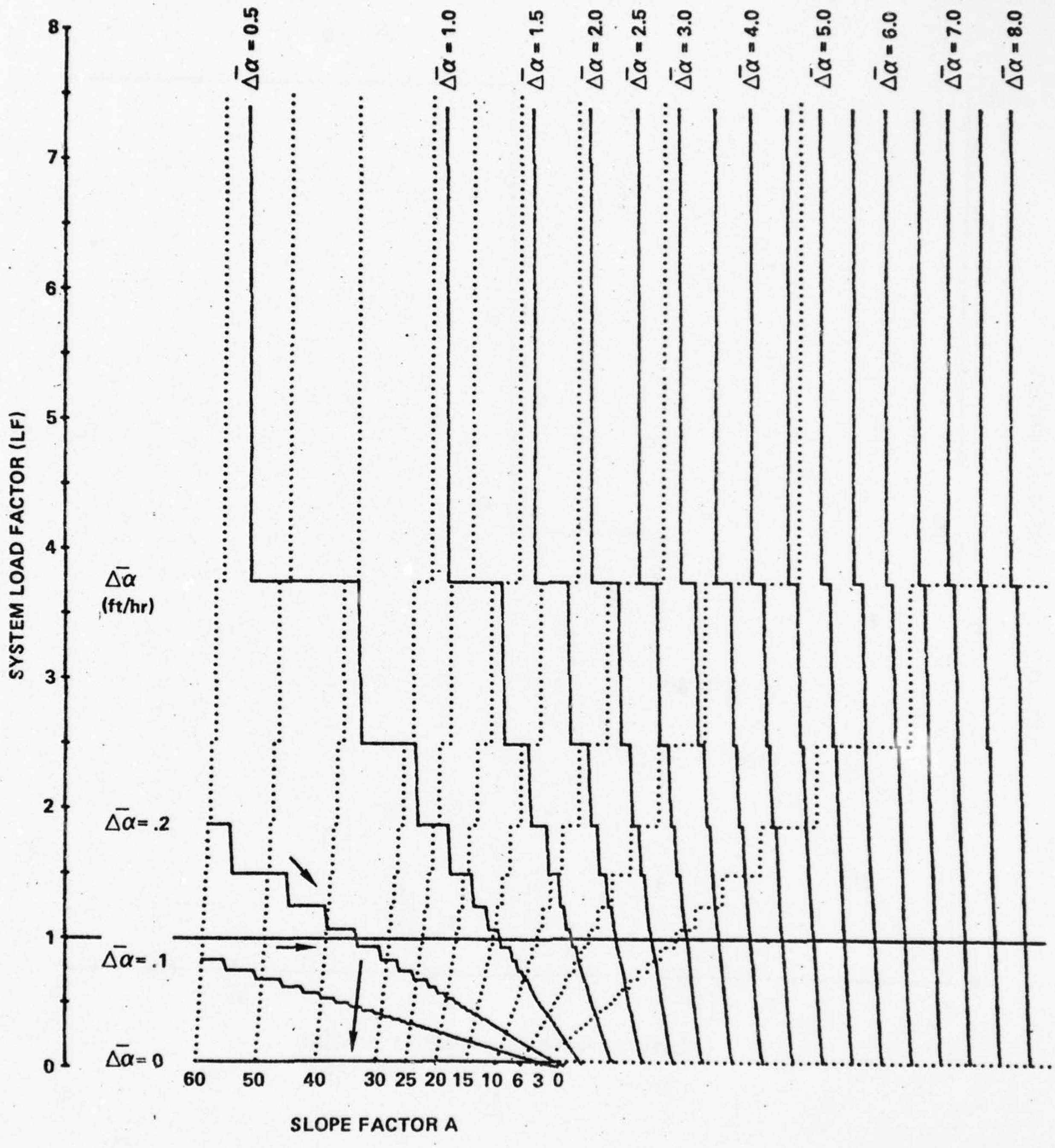


Figure 12. SYSTEM LOADING VS. SLOPE FACTOR

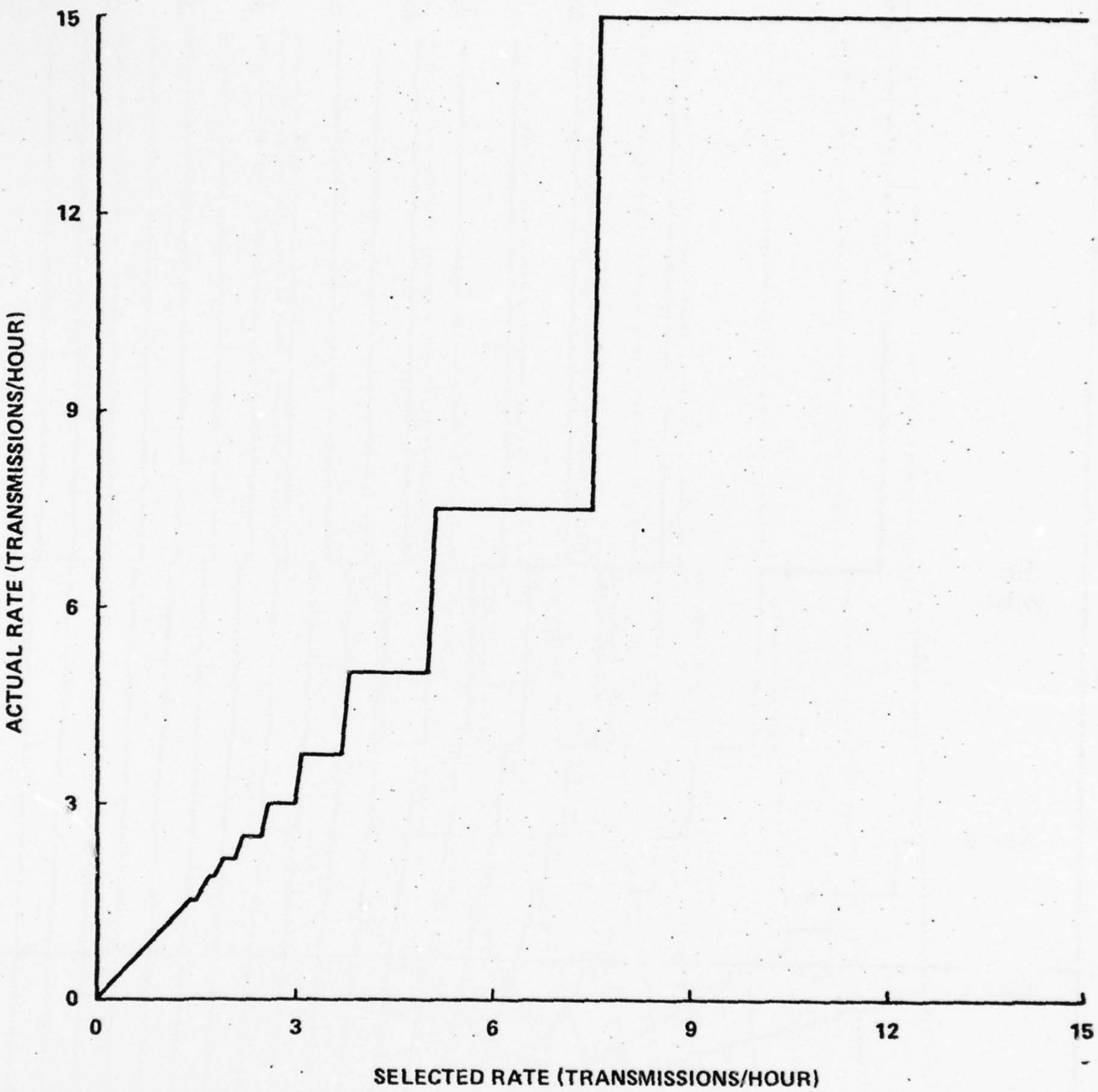


Figure 13. COMPARISON OF SELECTED RATE AND ACTUAL RATE

```
C********************************
C       LOFAK
C
C       ROUTINE TO SOLVE LOAD FACTOR
C       EQUATION FOR GOES RRDCS.
C
C       RMC & TDB      6 MARCH 1979
C
C********************************

        XFM=9999.

        ACCEPT 'LOAD FACTOR:  ',XLF
        ACCEPT 'BASE RATE:    ',R1
        ACCEPT 'RATE OF CHANGE:    ',DA

        LI=0
        AB=0.
        DO 120 K=1,2
        AS=10.**(2.-K)
        DO 100 I=0,9
        AT=AB+AS*I
        J=INT(15./(R1+AT*ABS(DA)*16./60.))
        IF(J.EQ.0)GO TO 100
        CLF=7.5/J
        DLF=CLF-XLF
        IF(ABS(DLF).LT.ABS(XFM))LI=I
        IF(ABS(DLF).LT.ABS(XFM))XFM=DLF
100     CONTINUE

        IF(LI.EQ.0)GO TO 120
        IF(XFM.EQ.0)GO TO 200
        IF(XFM.GT.0)LI=LI-1
        AB=AB+LI*AS
        LI=0
120     CONTINUE

200     WRITE(10,210)AB,XFM

210     FORMAT(/"    A=",F8.2,"       +/- "
,F7.4/)
        STOP
        END
```

microterminal, which can be used to perform the following functions:

- enter and display HEX number,
- enter and display decimal number,
- calibrate α,
- calibrate β,
- acquire data,
- transmit data, and
- measure forward radio frequency (RF) power and reflected RF power.

A sample checkout sheet for the RR/DCP and the procedures used to exercise the RR/DCP functions are presented in Appendix D.

Once the constants are entered into the RR/DCP and the instruments are calibrated, the DCP is ready to run. Operation of the DCP can be initiated by removal of the microterminal or by removal and reapplication of power with the microterminal removed. Either way, the RR/DCP will begin to operate and will send its first transmission within 2 min.

4. DEMODULATOR/BIT SYNCHRONIZER

The key to the operation of a random reporting system is the reduction of the transmitted message overhead time required to transfer one message word. Before now, the GOES DCS message structure has been:

5 sec unmodulated carrier (carrier acquisition),
2.5 sec alternating 1's and 0's (bit synchronization),

0.15 sec		frame synch word, (MLS sequence),
0.31 sec		31 bits of station identification, data (ASCII at 100 bits/sec),
.32 sec		3 EOT words,
8.04 sec		total message overhead time.

The data part of the message will require 0.12 to 20 sec depending on whether stored data techniques are used at the remote site. By far the largest portion of message overhead is in the unmodulated carrier and 1's and 0's pattern used by the demodulator to acquire carrier and bit synchronization. Therefore, it appears that the message length could be most readily reduced by decreasing those times. An increase in the data rate would also be an effective method for increasing efficiency when longer message lengths are required. Message length might be slightly decreased by eliminating the ASCII format and reworking the ID, MLS, and EOT formats.

In this effort, Sutron concentrated on applying new demodulator techniques to the reduction of carrier acquisition time and bit synchronization time. Sutron developed an approach that reduced both of these times; carrier time and bit synchronization time were each reduced to 0.5 sec.

A functional block diagram of demodulator carrier acquisition is shown in Figure 14. New circuitry was added to a standard phase-lock loop with a ramp search function. (This circuit approach is currently used in existing GOES DCS demodulators.) In this case the ramp search function* has been replaced by a circuit that measures the frequency difference between the voltage-controlled crystal oscillator

*Described in Phaselock Techniques, Floyd Gardner, John Wiley and Sons, 1966, New York, New York.

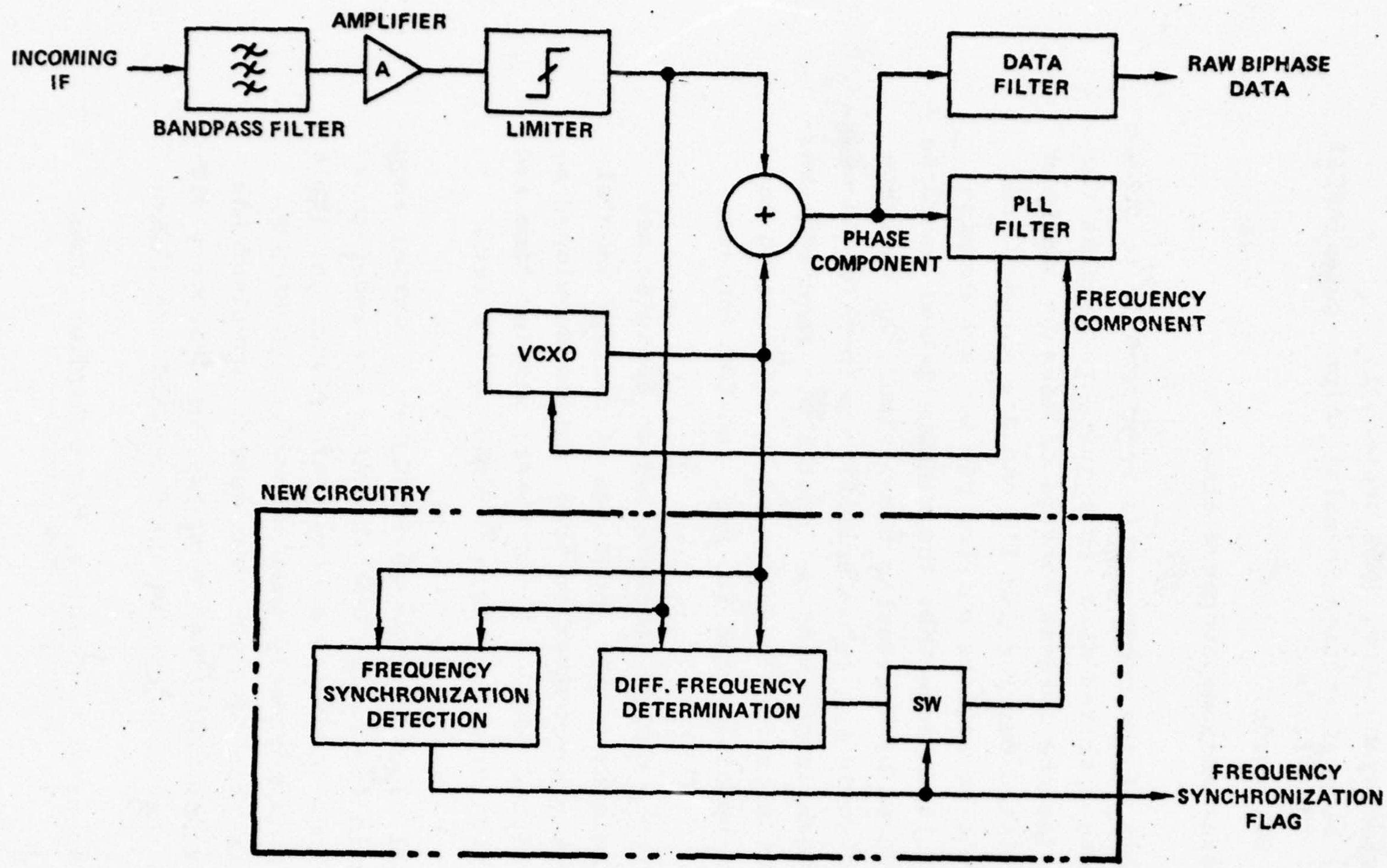


Figure 14. DEMODULATOR CARRIER ACQUISITION FUNCTIONAL BLOCK DIAGRAM

(VCXO) and the incoming signal. Prior to frequency lock, the predominant signal that is used to drive the VCXO originates from the frequency difference detection circuit. When the two frequencies are close (within the response time of the phase-locked loop filter) the phase error signal (shown as an exclusive or, $\oplus$, gate) is the primary VCXO driver.

When no signal is present, the circuit acts on the noise that passes through the filter. The noise frequency is evenly distributed about the center of the filter so that the VCXO slowly varies around the center of the band. This feature reduces the frequency search area by a factor of 2. The error signal sign and magnitude is directly proportional to the frequency difference so that as the difference becomes small, the error signal decreases, which in turn decreases the rate of closing of the VCXO and signal. The equations developed for previous ramp search circuit configurations still apply; however, they are significant only when the phase lock loop is approaching frequency and phase synchronization.

The basic concept employed is the separation of circuit functions that operate independently on each pertinent information set available. This same concept is further employed in the bit synchronization circuitry.

Data are encoded at each remote transmitter in a biphase format. The code is generated by digitally multiplying exclusive data with 100-Hz data clock. The generation of this code is shown in the top part of Figure 15, while the lower part of the figure shows the integral of the biphase resultant and data that are in perfect bit synchronization over one clock period. The integral of Bø is zero at the end of each clock period.

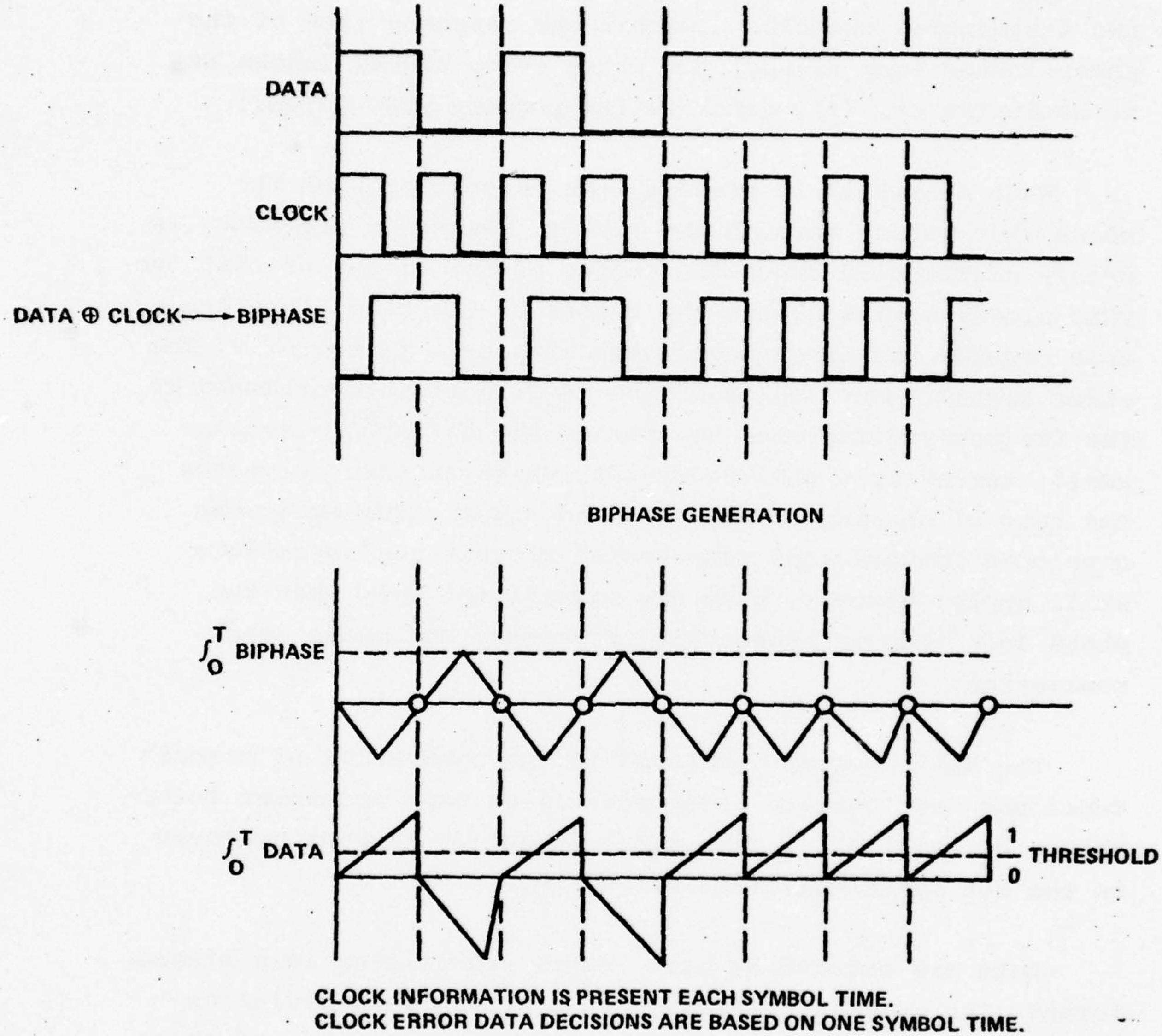


Figure 15. BIPHASE DATA GENERATION AND DEMODULATION

Figure 16 is an illustration of the generation of an error signal by a clock that is lagging the remote transmitter clock which is generating the biphase data. The error causes a non-zero answer from the integral at the end of the bit period. The value of this error voltage is proportional to the degree of phase desynchronization. This integral can only have non-zero value when there is a data transition. The polarity of this lack of phase synchronization is determined by combining the output of the data integral and Bø integral.

Since a key assumption is that the clock frequency is known, the unknown to be resolved is phase synchronization. Another assumption is that if phase synchronization can be made over three bit periods, a coherent signal is present. Current remote transmitter specifications require ±0.1 percent accuracy on the 100-Hz data clock. Since this data clock already must be generated by a crystal oscillator, it is recommended that either (a) the clock frequency be derived from the transmitter oscillator so that at the demodulator once frequency synchronization occurs, then the VCXO can provide the matching data or (b) that the specifications be modified to require data clock frequency to be accurate to within ±.01 percent. The latter method is more easily accomplished since 0.01 percent accurate crystal oscillators are common.

Figure 17 is a functional block diagram of the demodulator bit synchronizer and data decoder. The new element is the digital phase shifter, which is proportionally driven by the Bø integral error signal. Previous designs use a digitally stepped VCXO, an approach that produces less than optimum clock acquisition and tracking performance because the phase is unknown rather than the frequency.

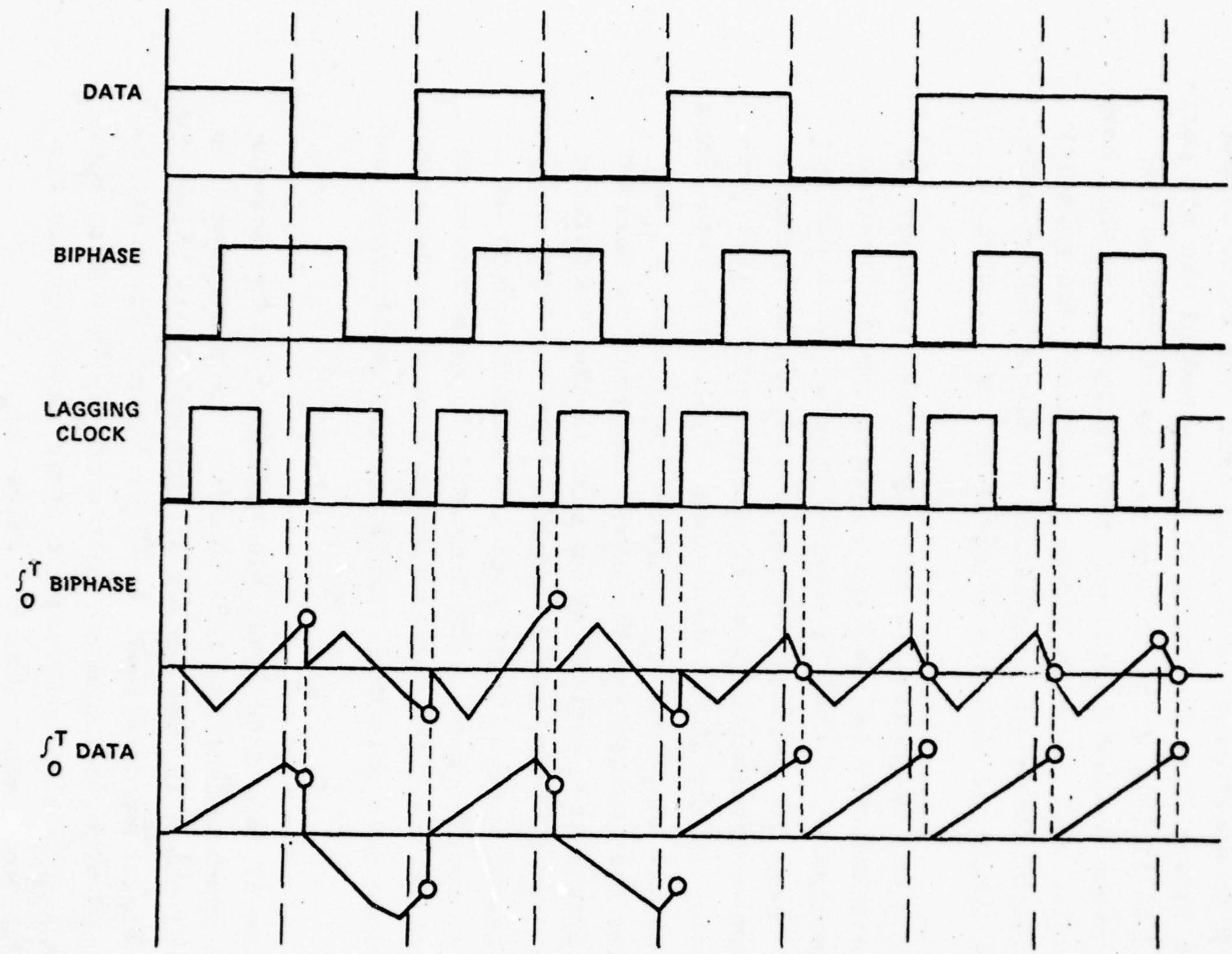


Figure 16. BIPHASE CLOCK GENERATION SYNCHRONIZATION ERROR SIGNAL

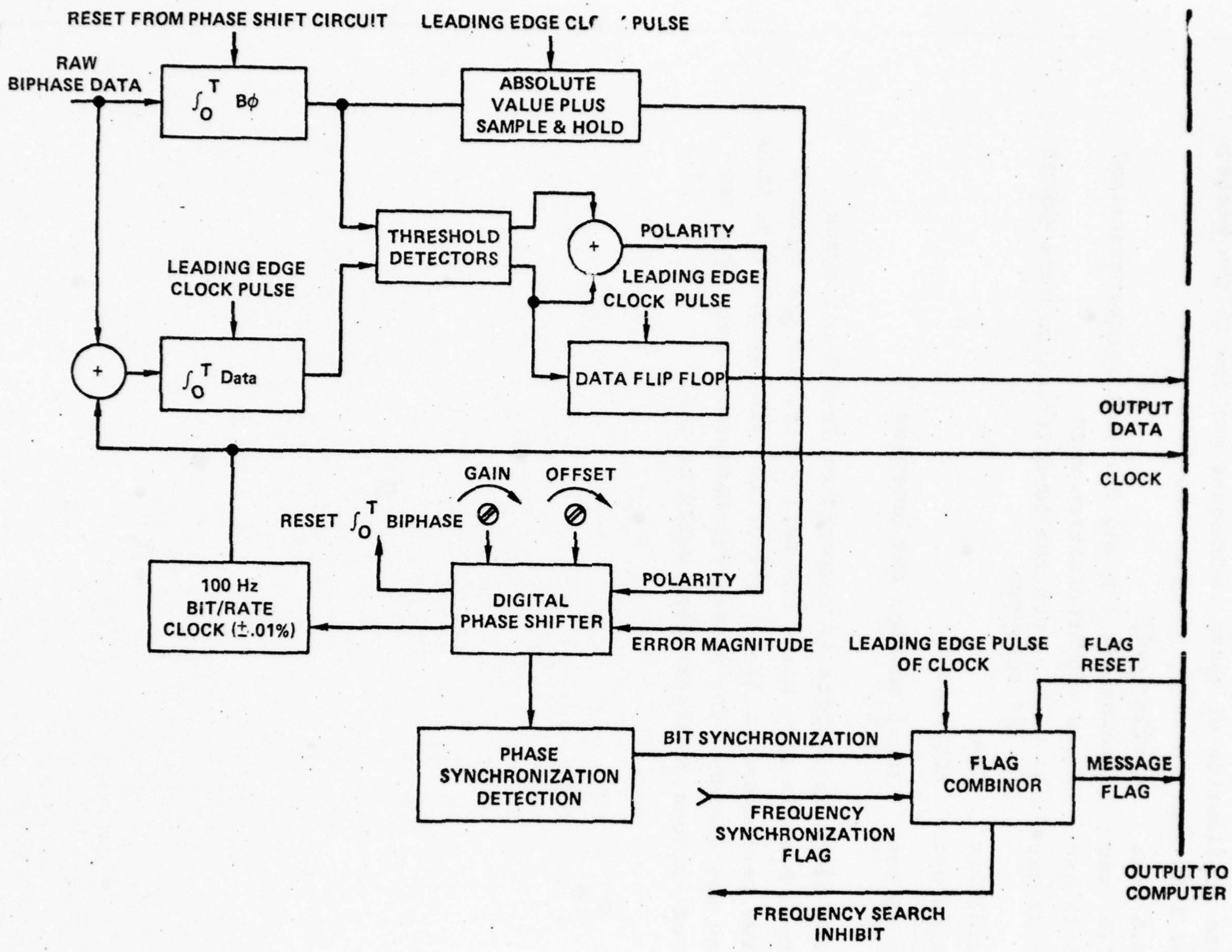


Figure 17. FUNCTIONAL BLOCK DIAGRAM OF DEMODULATOR BIT SYNCHRONIZER AND DATA DECODER

The application of these techniques has led to the message size of 1.86 sec. It is composed of the following:

0.5 sec	carrier only
0.5 sec	alternating 1's and 0's (bit synchronization)
0.15 sec	frame synchronization word
0.31 sec	31 bits of station identification data (ASCII at 100 bits/sec)
0.32 sec	data
0.08 sec	EOT word
1.86 sec	total message and overhead

The data block of 32 bits is composed of four 8-bit bytes. Each byte has six data bits, one parity bit, and one control bit. Two parameters of 12-bit resolution are transmitted. This message was designed for system demonstration, but other messages of various configurations could be used.

V. ERROR DETECTION AND CORRECTION

Each bit decision i.e., the decision whether the symbol period contains a 1 or 0 is made over one-clock period only. The energy is integrated over the entire period and a 1 or 0 decision is made based on the value of the integral. Figure 16 graphically shows the development of that integral which is identified by the $\int_0^T$ data terminology. The value of that integral also shows the likelihood or probability that a correct decision was made. By observing the output of that circuit on an oscilloscope, one can assess the quality of the message. Assigning value equal to the integral value to that bit in addition to the one/zero symbol would add a quality indicator to each bit which would point to message areas that would have a high probability of error.

Each data byte also includes an odd parity bit plus a bit which is always a one. Checking these bits is also an error indicator.

Probably one of the best overall indicators is to compare the received parameter value with that received in previous messages coupled with an expected parameter change over the given time period. Expected parameter change could be derived from known situation configurations and data derived from interstation relationships, e.g., a station located upstream or downstream from the station in question.

Further improvements in error detection/correction can only be attained through the addition of information to the transmitted message. This can take the form of additional parity data which could be used to correct single bit errors per 64-bit block or of convolutionally encoding transmitted

data so that bit decisions could be spread over greater than one clock period. Operating a decoder (such as that offered by Linkabit Corp.) uses an integration length of 7-clock periods and a code rate of 2, i.e., two bits are transmitted for every data bit. This has the disadvantage of requiring twice as much data to be transmitted (3 dB data rate loss) but since error correction can be made, there is a design gain of 4.6 dB in equivalent signal-to-noise performance for a net gain of 1.6 dB.

Automatic monitoring of signal quality indicators such as the bit decision integral can be used to operate a directed maintenance program which may significantly alleviate the problem of data loss caused by malfunctioning remote sites.

VI. RANDOM REPORTING TEST DEMONSTRATION

The culmination of the Sutron design and development of a random reporting data collection system was a demonstration of the reception of data from the equivalent of at least 200 remote sites transmitting twice an hour. This demonstration was performed in conjunction with the New England Division of the U.S. Army Corps of Engineers GOES DCS downlink at Waltham, Massachusetts. The receiving dish size was 15 feet; the preamp had a $280^{o}K$ noise temperature; and the phase-lock receiver was designed by FG Engineering, Inc. The probability of successful reception of a single message was 0.684 (i.e., the probability of failing to receive one message would be 0.316; this would provide a probability of 0.90 of receiving data from a given station in 1 hr if the remote unit transmitted twice an hour). Three transmitters were programmed to randomly transmit 160 times an hour with a 1.86-sec message. The theoretical probability of successfully receiving each transmitted message is calculated to be 0.69. Before each remote station transmission, a counter was incremented once and transmitted as the precipitation reading so that the number of transmissions from each remote unit was known. A sample of the received data is shown in Table 5. In total, about 8,000 messages were transmitted over a 2-day test period. An hourly summary of these data is presented in Appendix E.

Two data periods - 0700 to 0803 on 12/7/78 and 0610 to 0730 on 12/8/78 - were closely analyzed. Summary data on the 12/7 period is shown in Table 6. Of the 386 transmissions sent, 287, or 74.4 percent, were successfully received. Figure 18 is a plot of 10-min groupings of performance during the 8 December

Table 5. SAMPLE OF DATA COLLECTED DURING THE RANDOM REPORTING TEST DEMONSTRATION

Received ID	Demodulator Channel No.	Date	Reception Time	Raw Hex Data	Transmission Count	Stage Input
995C575E	CHANNEL: 4	12/ 7/78	22:19:51	52C452E904 PPT=	2.74	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:20:16	7661404004 PPT=	21.66	STAGE= 0.00
995C574E	CHANNEL: 4	12/ 7/78	22:20:31	F761404004 PPT=	21.67	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:20:46	D3C452E984 PPT=	2.75	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:21:11	F861404004 PPT=	21.68	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:21:34	54C452E904 PPT=	2.76	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:21:43	7961404004 PPT=	21.69	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:21:54	D5C452E904 PPT=	2.77	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:21:59	FB61404084 PPT=	21.71	STAGE= 0.00
995C574E	CHANNEL: 4	12/ 7/78	22:22:13	7C61404004 PPT=	21.72	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:22:24	D6C452E904 PPT=	2.78	STAGE= 26.42
995C534E	CHANNEL: 4	12/ 7/78	22:22:48	FD61404004 PPT=	21.73	STAGE= 0.00
995C573E	CHANNEL: 4	12/ 7/78	22:22:50	E0C4404084 PPT=	2.88	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:22:58	57C452E904 PPT=	2.79	STAGE= 26.42
995C573E	CHANNEL: 4	12/ 7/78	22:23: 7	61C4404000 PPT=	2.89	STAGE= 0.00
995C574E	CHANNEL: 4	12/ 7/78	22:23:43	FE61404004 PPT=	21.74	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:23:53	DAC452E906 PPT=	2.82	STAGE= 26.42
9978574E	CHANNEL: 4	12/ 7/78	22:24:36	[illegible]765444006 PPT=	24.23	STAGE= 0.04
995C554E	CHANNEL: 4	12/ 7/78	22:25:26	4062404004 PPT=	21.76	STAGE= 0.00
995C574E	CHANNEL: 4	12/ 7/78	22:25:29	C162404004 PPT=	21.77	STAGE= 0.00
995C574E	CHANNEL: 4	12/ 7/78	22:25:37	C262404004 PPT=	21.78	STAGE= 0.00
995C574E	CHANNEL: 4	12/ 7/78	22:25:41	4362404044 PPT=	21.79	STAGE= 0.00
995C574E	CHANNEL: 4	12/ 7/78	22:26:10	D462404004 PPT=	21.96	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:26:21	5EC452E904 PPT=	2.86	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:26:24	4562404004 PPT=	21.81	STAGE= 0.00
995C574E	CHANNEL: 4	12/ 7/78	22:26:48	4662404004 PPT=	21.82	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:27:12	DFC452E984 PPT=	2.87	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:27:39	C762404004 PPT=	21.83	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:28: 9	E0C452E984 PPT=	2.88	STAGE= 26.42
995C575E	CHANNEL: 4	12/ 7/78	22:28:27	61C452E904 PPT=	2.89	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:28:34	C862404004 PPT=	21.84	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:28:37	[illegible]DC452E904 PPT=	2.90	STAGE= 26.42
995C575E	CHANNEL: 4	12/ 7/78	22:28:57	[illegible]3C452E904 PPT=	2.91	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:29: 3	4962404084 PPT=	21.85	STAGE= 0.00
995C575E	CHANNEL: 4	12/ 7/78	22:29:25	E5C452E904 PPT=	2.93	STAGE= 26.42
995C574E	CHANNEL: 4	12/ 7/78	22:29:49	4A62404004 PPT=	21.86	STAGE= 0.00

Table 6. SUMMARY DATA TAKEN ON 7 DECEMBER 1978

Transmitter Identification	Transmissions	Number Received	Percent Received
995C575E	137	87	0.635
995C574E	122	103	0.844
995C571E	127	97	0.764
Composite	386	287	0.744

Theoretical Probability (from Eq. 1):

$$P_s = e^{\left|\frac{-2tm}{T}\right|} \qquad \text{(Eq. 1)}$$

$M = 3$;

$t = 1.86$; and

$$T = \frac{3767}{386} = 9.76 \text{ sec for three sites or } 29.28 \text{ for one site}$$

$$P_s = e^{\frac{-(2)(3)(1.86)}{29.28}} = e^{-0.381} = 0.683$$

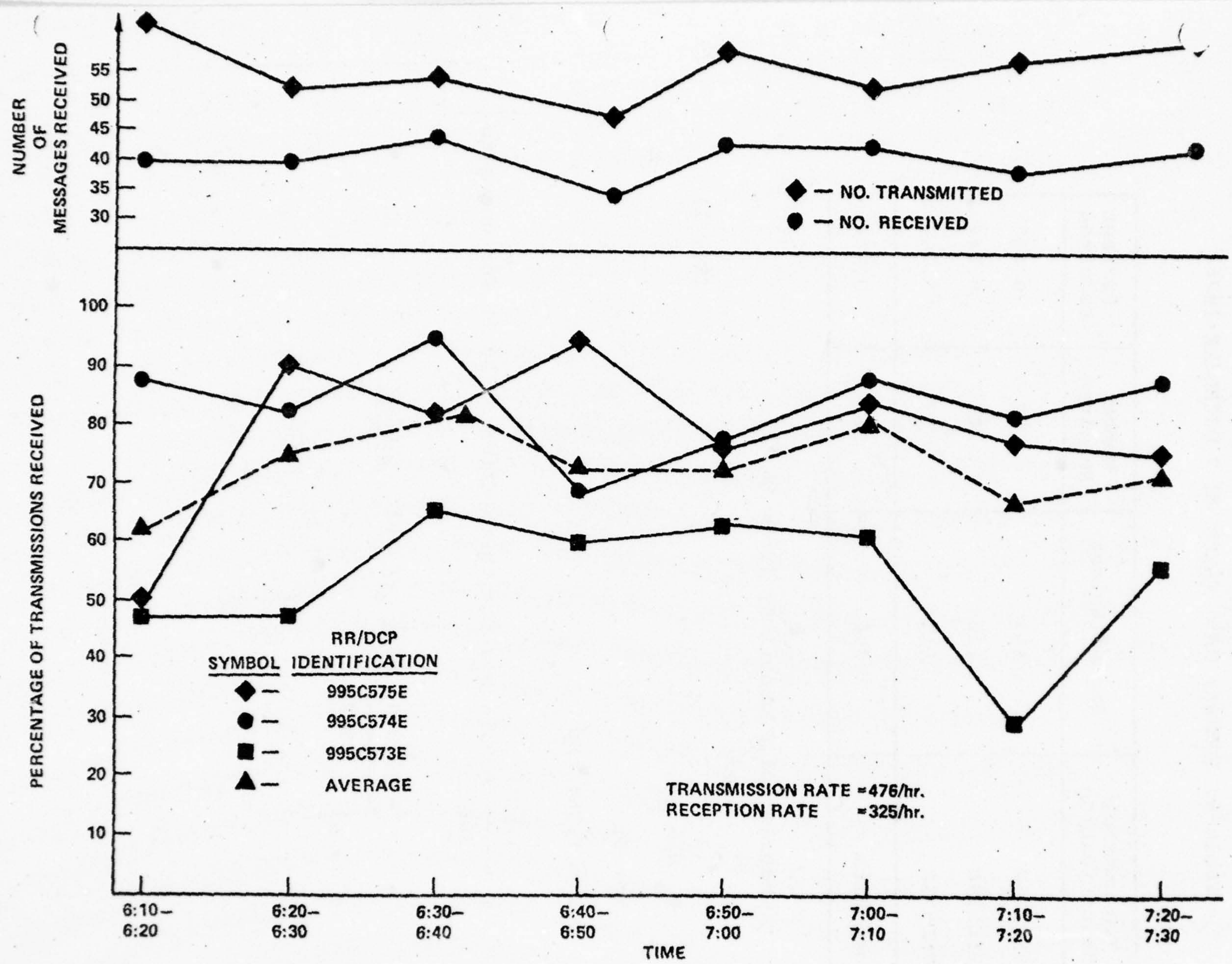


FIGURE 18: RANDOM REPORTING PERFORMANCE TEST

period. Summary calculations for this period are made in Table 7. Theoretical calculations indicated that 68.9 percent of data should have been received, and 68.3 percent of the data were received during this experiment period. Thus, theory and experimental results are in very close agreement.

Table 7. THEORETICAL COMPUTATIONS (FROM EQ. 1)

$$P_s = e^{\frac{-2tM}{T}} \qquad \text{(Eq. 1)}$$

$t = 1.86$ sec

$$T_{system} = \frac{80\text{x}60 \text{ sec}}{476 \text{ transmissions}} = \sim 10 \text{ sec}$$

$T_{unit} = 30$ sec

$M = 3$

$$P_s = \frac{-(2)\ (1.86)\ (3)}{30} = e^{-0.372} = 0.689$$

P_s (theoretical) $= 0.69$

$$P_s \text{ (experimental)} = \frac{325}{476} = 0.683$$

Two practical phenomena were observed but did not seem to significantly impact the overall results.

(1) The effective message length is expected to be slightly less than 1.86 sec since frequency acquisition takes place in less than the allotted 0.5 sec and lost EOTs are not seen. $T_{eff} = 1.7$ sec + $P_s = 0.71$. This may be affected somewhat by the release time of the demod ; and

(2) transmitter 3E was at times over ridden by 5E or 4E which had stronger power output.

VII. SUMMARY

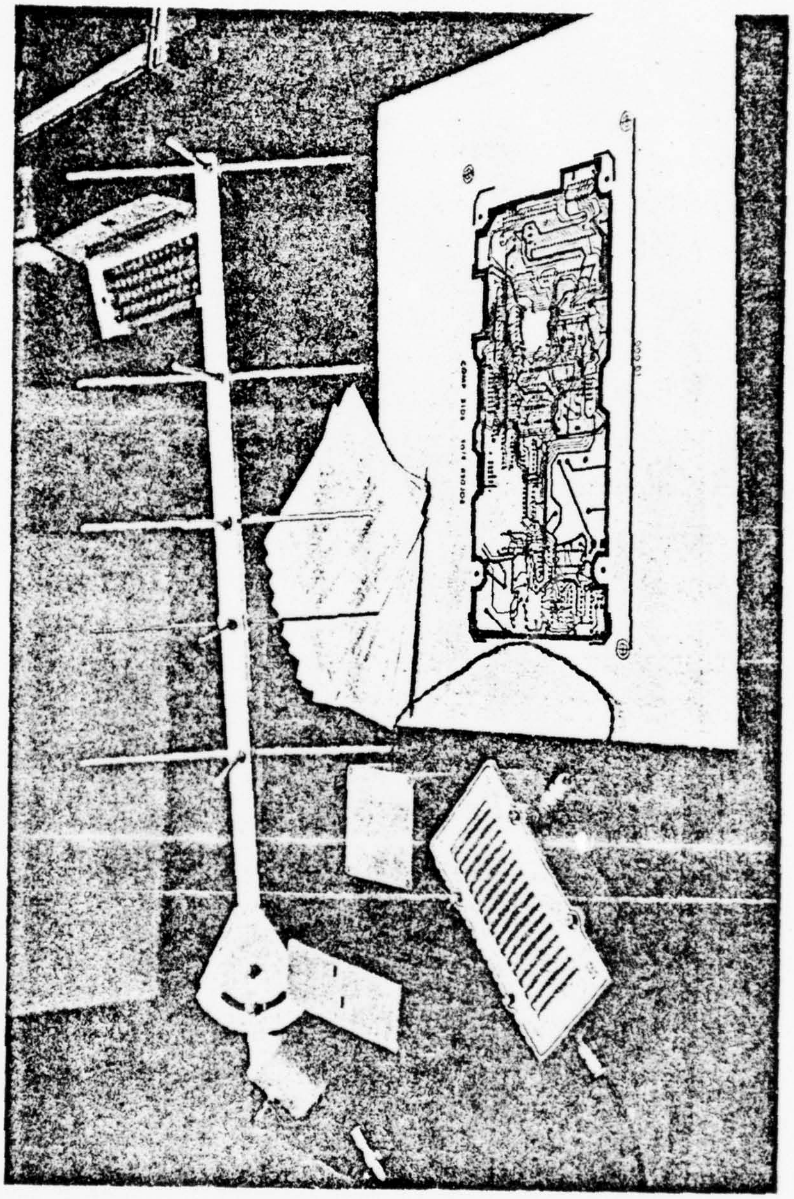
The demonstration of random reporting showed that the probability equations used to describe system performance are credible; experimental and theoretical results were virtually identical. Any further improvements in reducing the message length can be calculated from the theoretical equations given.

The addition of adaptive capability to the remote platform permits tailoring of data throughput to parametric activity. This tailoring results in improved communication channel usage as well as in improved response time to events of interest. This response time, i.e., time to receipt of data, may be as short as a few minutes. Total channel performance given in Figures 5 and 6 show the relative safety in determining remote site reporting rate algorithm coefficients. Even if the average reporting rate is somewhat higher than expected, no disaster will befall the channel performance; only slow degradation will take place.

The performance achieved exceeds that required in the modified statement of work, i.e., from a field of 240 stations operating at two transmissions per hour, the probability of message reception in any given hour for a single station will be 90 percent. This was demonstrated by an equivalent system configuration. An experimental value of probability of failure of one message was 0.316, which gives a probability of failure from the reception of any two messages to be $(.316)^2$ or 10 percent, the resultant probability of success to be 90 percent. Better channel performance can be achieved by defining the observed throughput in terms of average throughput per transmitter. In this case, about 325 transmitters could be accommo-

dated per channel, transmitting at an average rate of two transmissions per hour.

Development of adaptive random reporting operation resulted in a remote transmitter which has considerably reduced parts count (19 small-scale integrated circuit packages and 10 large-scale integrated circuit (IC) packages, total circuit board area required is about 120 in.^{2} - previous implementation required about 78 IC's and 240 in.^{2} of circuit board area) and reduced power consumption. Power consumption required by self-timed units is about 250 milliwatts and for the random reporting unit reporting twice per hour is about 36 milliwatts - a sevenfold improvement. Power consumption to one-half this value is reasonable to expect with some further development.



ADAPTIVE RANDOM REPORTING DCP

APPENDIX A

DISCUSSION OF ADAPTIVE RANDOM REPORTING

The equation that describes adaptive random reporting system performance was derived in the Computer Sciences Corporation* (CSC) study done for the National Aeronautics and Space Administration (NASA) LANDSAT Data Collection System. It takes into account spectral as well as time dispersion. Since Sutron is considering only one-channel operation, time dispersion is of interest. If more than one demodulator is operated on a channel, it would be feasible to consider increasing channel capacity by spectral dispersion. However, this can only be accomplished if some improvement can be made in the modulation technique to reduce spectral splatter caused by binary phase modulation.

If one data collection platform (DCP) is transmitting, there is a finite probability that a second DCP transmission may interfere with the first. If there is no relationship between the two transmission times, the probability of failure is**

$$Pf_1 = \frac{2t}{T}$$

and

$$\overline{P}f_1 = 1 - \frac{2t}{T}$$

* ERTS-A Data Collection System Description, prepared for NASA Goddard Space Flight Center, Contract No. NAS-5-11242, Computer Sciences Corporation.

**Ibid.

where

t = transmission time and

T = remote transmitter off time.

The probability of no interference from M DCPs is

$$P_{sm} = (\bar{P}f_1)^M$$ probability of successful reception in a field of M interferers

where

P_{sm} = probability of successful reception in a field of M interferers and

M = the number of interfering transmissions.

The probability of being interfered with by M DCPs is

$$P_{fm} = 1-P_{sm} = 1-(Pf_1)M = 1 - (\frac{2t}{T})^M$$

where

P_{fm} = the probability of failure in a field of M interferers.

If one DCP tries to transmit n times during the observation period, then

$$\bar{P}_{fm} = \{1- (1 - \frac{2t}{T})^M\}^n.$$

Now from series expansion, where $\alpha = \frac{2t}{T}$,

$$(1-\alpha)^M = 1 - \alpha M + \frac{\alpha^2}{2} M (M-1) - \frac{\alpha^3}{2} (M) (M-2).$$

If M is large, then

$$(1-\alpha)^M = 1 - \alpha M + \frac{\alpha^2 M^2}{2} - \frac{\alpha^3 M^3}{3} + \ldots,$$

which is the same expansion as $e^{-\alpha M}$. Now substituting back

$$P_{fm} = (1 - 3\frac{-2tM}{T})^n.$$

As can be seen, the object of this exercise is to develop a manageable equation that is generally applicable. Since it is possible to select the observation period (unlike a polar orbiting satellite), we need go no further with the development of the equation. Now the probability of successfully receiving a single message is (m suffix dropped)

$$Ps = 1 - Pf$$

or

$$Ps = 1 - (1 - 3 - \frac{2tM}{M})^n$$

where

- Ps is the probability of successfully receiving a transmission in a given observation time,
- n is the number of transmission tries in the observation time,
- t is the length of each transmission,
- T is the time interval between transmissions, and
- M is the number of transmitters operating in the channel of interest.

The following two curves are different presentations of this equation. A few example calculations for Figure 1 are:

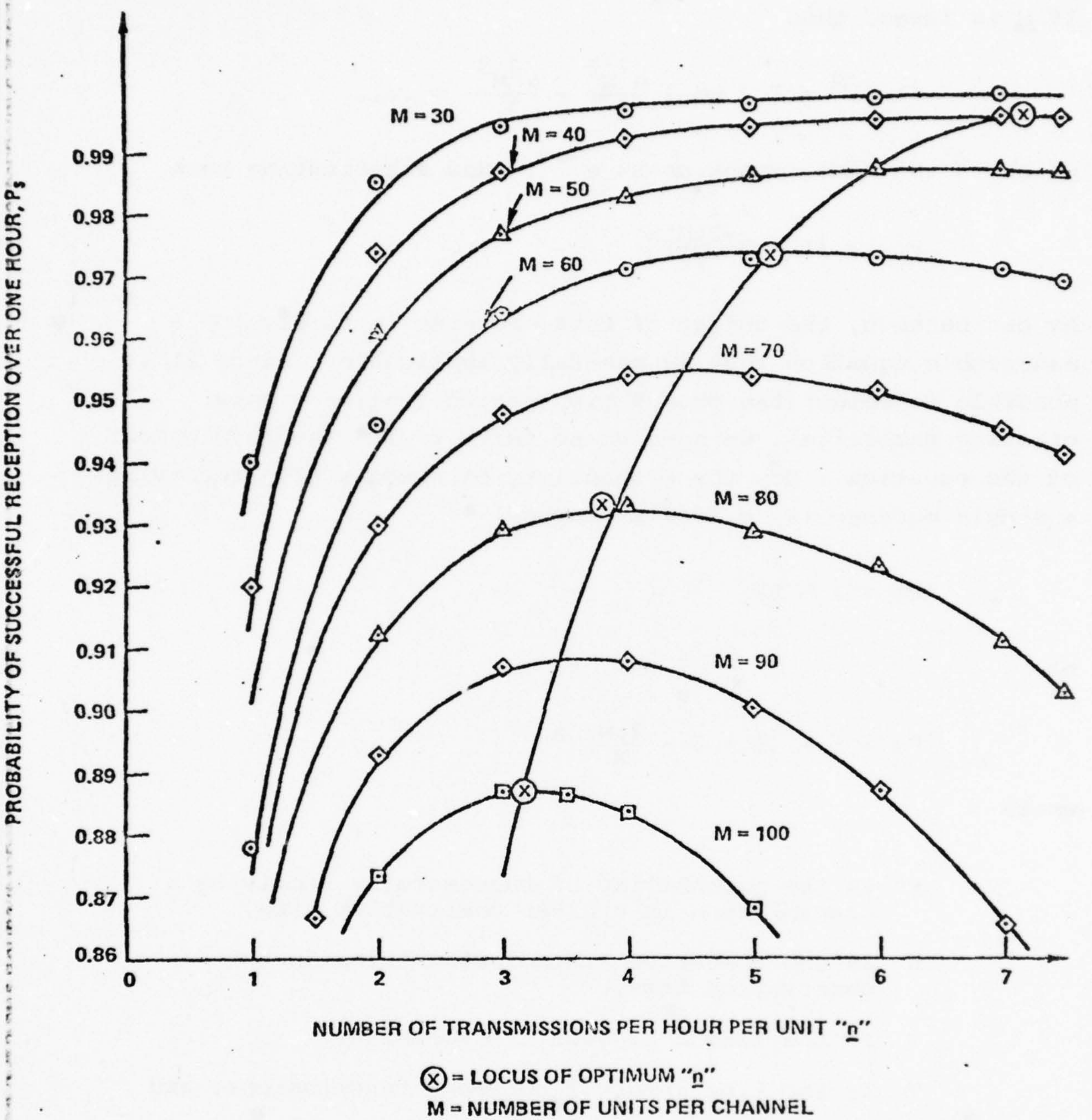


Figure 1

Plot of $Ps = (1 - e^{\frac{-2tM}{T}})^n$

n = variable 1-7
M = variable 30-100
t = 4 sec
T = 3600 sec/n

Example 1: $n = 2$ $\quad t = 4$

$M = 100$ $\quad T = 3600/2 = 1800$

$$Ps = 1 - (1 - e^{-(2x4x100) - 1800})^2$$

$$= 1 - (1 - e^{-.444})^2 = 1 - (1 - .64)^2$$

$$= 1 - (.36)^2 = 1 - .128$$

$$Ps = .872$$

Example 2: $n = 3$ $\quad t = 4$

$M = 50$ $\quad T = 3600/3 = 1200$

$$Ps = 1 - (1 - e^{-(2x4x50) - 1200})^3$$

$$= 1 - (1 - e^{-.333})^3 = 1 - (1 - .717)^3$$

$$= 1 - (.283)^3 = 1 - .023$$

$$Ps = .977$$

For a fixed regime random reporting system this curve suggests that for a maximum throughput about three transmissions per window are required but, if slightly lower throughput is permissible by 1 or 2 percent, then power consumption can be reduced by about 30 percent. If too many messages are transmitted, throughput can actually decrease, but not sharply.

Figure 2 uses the probability of failure of a single message as a performance index for a fixed regime random reporting system. These curves can be read several ways. First, select a desired Pf and read up to the number of permissible stations reporting a four-second message three times per hour; e.g., if $Pf_1 = .5$;

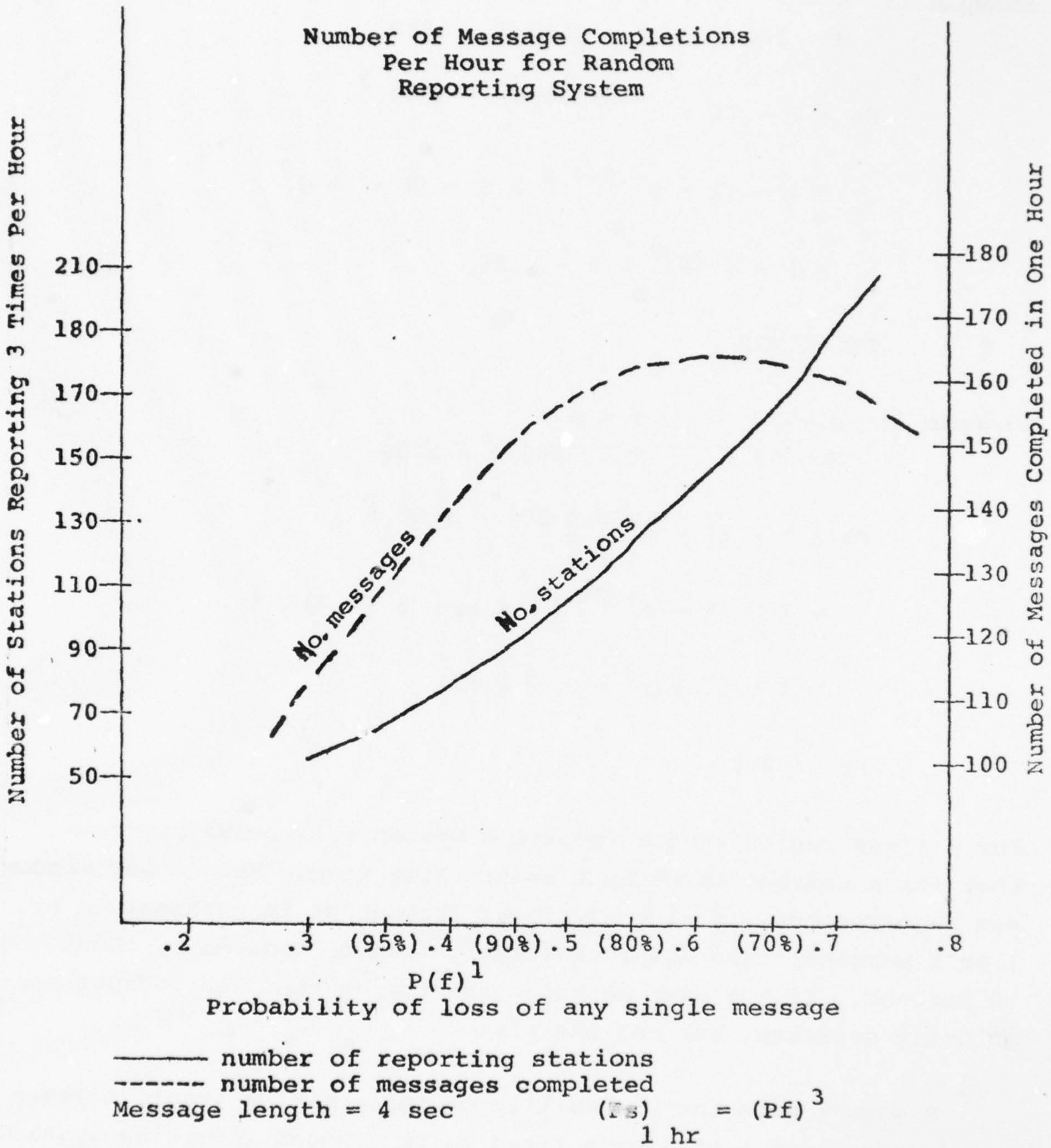


Figure 2. RANDOM REPORTING DCS SYSTEM THROUGHPUT

$M = 100$, number of completed messages = 150, and if $\underline{M}$ is selected as 150, $Pf_1 = .68$, and the number of completed messages is 160. Two calculation examples are:

Example 1:

$$Pf_1 = 1 = 3^{-2tM/T}$$

$$e^{-2tM/T} = 1-Pf_1$$

$$\frac{-2tM}{T} = \ln (1 - Pf_1)$$

$$M = \frac{T}{2t} \ln (1 - Pf_1)$$

for $\quad Pf_1 = .5,\ t = 4,\ T = 1200$

$$M = -\frac{1200}{8} \ln (.5) = -150 (\ln .5)$$

$$M = -\ln (-.69) = 104$$

If a large number of transmission samples are made then the total number of received messages for a sample period is the total number of messages transmitted times the probability of successful reception. For this case:

$$N_R = (.5)(104)(3) = 156$$

Example 2:

$$M = 150,\ t = 4,\ T = 1200$$

$$Pf_1 = 1 - e^{-2tM/T} = 1 - e^{-(2x4x250) - 1200}$$

$$Pf_1 = 1 - .368 = .632$$

$$\text{Total messages } N_R = (1 - .632)(150 \times 3)$$

$$N_R = 166$$

These numbers approximately agree with those picked from the curves.

Figure 3 shows the cumulative probability of reception of a single DCP operating in a fixed regime three messages per hour mode. For a system with 104 DCPs operating on a channel where $Pf_1 = .5$, 50 percent of each group of 10 messages will have 5 or more completed messages, and also 10 percent of each group of 10 will have 7 or more and 90 percent will have 3 or more messages complete, or otherwise stated there is about a 90 percent change of receiving one of three transmissions. From these three curves, the nature of any fixed regime random reporting design can be determined by manipulating the exponential coefficient $\frac{2tM}{T}$. For example, the coefficient will be identical if t is multiplied by one-half and M multiplied by two.

To verify that this equation is correct a hypothetical fixed regime system was modeled using computer generated random numbers.

The characteristic equation for the random reporting system is:

$$P_s = 1 - (1 - e^{-2tM/T})^n$$

Although this equation accurately describes system performance, an actual model of the system performance would provide better evidence that it does work.

The system design gives the following calculated values when $M = 130$, $P_s = 0.927$

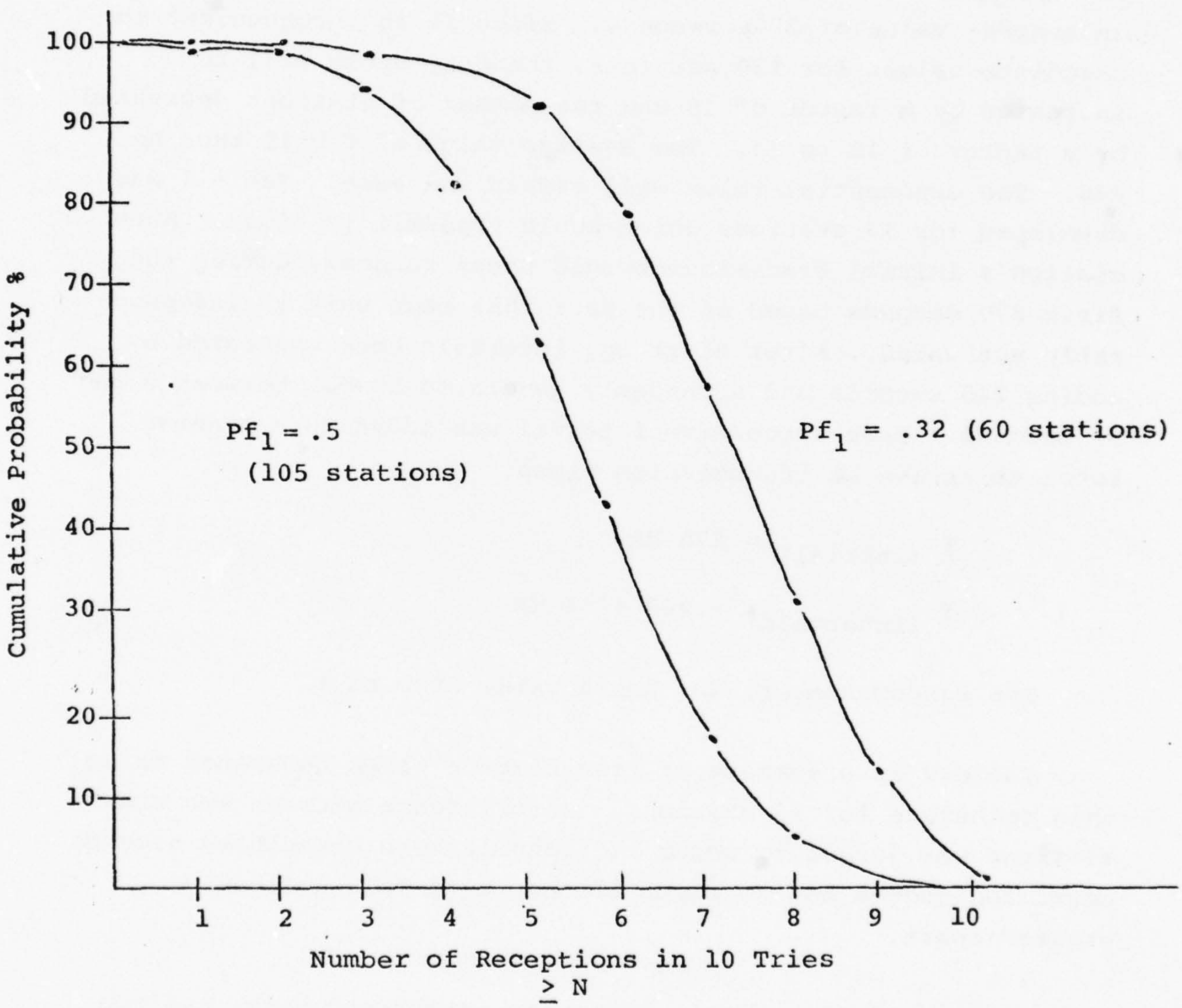


Figure 3. CUMULATIVE PROBABILITY FOR RECEPTION $\geq$ N IN 10 TRIES FOR A SINGLE DCP

$n = 2,$ $P_{f1} = 0.27$ Observation Time = 1½ hour

$T = 2700$ sec, $P_{fs} = 0.073$

$t = 3.4$ sec, $P_{f3} = 0.0188$

The approach is to generate random transmission intervals with an average value of 2700 seconds. Since it is inconvenient to calculate values for 130 stations, the duty cycle will be increased by a factor of 10 and the number of stations decreased by a factor of 10 to 13. The average value of T will then be 270. The exponential value will remain the same. Table 1 was developed for 13 stations which would transmit 13 times. Each station's initial transmissionwould occur randomly during the first 270 seconds based on the fact that each unit is independently activated. After start up, intervals were generated by adding 243 seconds and a randomly generated number between 0 and 54 seconds. Each successive interval was added to a running total to arrive at transmission times.

$$T_{(initial)} = 270\ NR$$

$$T_{(intervals)} = 243 + 54\ NR$$

The random number, NR, has a value of 0 to 1.

Table 2 is a summary of transmission times generated using this technique for 13 stations. Interference between two transmissions was judged to occur if transmissions were three seconds apart and judged not to occur if they were four seconds or greater apart.

A total of 45 transmissions were interfered with, and two transmissions interfering twice in a row occurred ten times. Dividing these numbers by the number of possible transmissions gives:

$$Pf_1 = 0.266,\ Pf_2 = 0.064,\ Pf_3 = 0.019.$$

Table 1. RANDOM TRANSMISSION TABLE

No. Failed Transmissions	Unit No. \ Transmission No.	1	2	3	4	5	6	7	8	9	10	11	12	13
2	1	15	299	576 X	834	1077	1373	1628	1904	2159	2455 □	2736	3033	3316
4	2	118	386	658	953	1233 X	1490	1755 X	2000 X	2292	2540	2826	3119 X	3375
1	3	195	433 X	722	998	1214	1533	1795	2061	2328	2584	2838	3084	3340
3	4	166	433 X	691	938	1231	1475	1729	1982	2276	2568 X	2861	3118 X	3390
5	5	243 X	535	790	1053 X	1307 O	1551 X	1847	2111 O	2403	2695	2942	3217	3510
7	6	201	457	705	962 O	1235 X	1483	1757 X	2002 X	2298	2566 X	2809 X	3105	3363 X
3	7	172	435 X	678	964 O	1218	1465	1738	1995	2258	2514	2807 X	3072	3358
2	8	64	329	57[illegible] X	848	1132	1419	1697	1964	2241	2526	2801	3088	3362
6	9	245 X	519 O	794	1047 □	1290	1548 O	1842	2114 O	2360	2614	2908	3182 O	3448
4	10	219 O	516 O	810	1056 X	1348	1635	1889	2181	2458 □	2705	3001	3255	3521
3	11	152	437 X	734	992	1284	1547 O	1834	2118	2366	2643	2887	3179 O	3475
3	12	206	499	772	1058 X	1304 O	1552 X	1826	2103	2387	2663	2917	3191	3461
2	13	221 O	506	754	1049 □	1315	1599	1872	2129	2382	2677	2973	3228	3491
45	No. Interfered With	4	6	2	7	4	4	2	4	1	3	2	4	2 /45

$$P_{f_1} = \frac{45}{169} = 0.266$$

$$P_{f_2} = \frac{10}{156} = 0.064$$

Rule: Within 3 Sec. Have Interfered
4 Sec. or Greater No Interference

X, O, □ } Denotes Transmission Interfered With

The results from the random model are extremely close to the calculated answers. If additional stations and a greater number of transmissions were calculated, the number of interferences per station will be closer to calculated values.

ADAPTIVE RANDOM REPORTING

Now that a fixed regime random reporting network has been fully described, it is fairly easy to make the jump to an adaptive rate random reporting system if the randomness hypothesis is maintained, i.e., even if a station transmits at a higher rate, it is equivalent to two stations transmitting at a one-half rate. From the previous curve, Figure 2, it can be seen that a random reporting channel can be said to be at maximum utilization when 160 stations are transmitting at three times an hour a four-second message, or otherwise stated 480 messages transmitted, one-third received, 1920 seconds total on transmitter time, for a total approximate channel busy time of 50 percent. A more power conservative operating region is to operate at an equivalent 104 station load, or about 312 messages per hour transmitted with 156 receptions and a 50 percent probability of reception of each transmitted message. This channel characterization would be true for any mix of DCPs which randomly generate 312 messages of four-second length per hour.

APPENDIX B

DEMODULATOR ENGINEERING SPECIFICATIONS

INPUT

Frequency - Pilot tone center is at 10.000 MHz. Each input channel is located with respect to the 10 MHz intermediate frequency
Power: 0 dBm to -40 dBm

Power Supply - ±5 volts at 5% tolerance
+5 volt requires .4 amps
-5 volt requires .2 amps

Performance - Carrier acquisition time - <.5 sec with incoming frequency within ± 600 Hz of channel center.

Bit synchronization time - <.5 sec with incoming data rate within .1% of 100 Hz clock rate.

Signal/noise - performance dependence on signal to noise ratio of incoming signal not as yet established.

OUTPUT

3 lines presented to a serial computer port which is interrupt driven.

Line #1 - Data - positive logic

Line #2 - Interrupt flag - negative logic - The presentation

of this flag means that both frequency and bit synchronization are present and that data has been clocked into the output flip-flop. The computer has 10 milliseconds (one clock period) to acquire this data bit.

Line #3 - Reset line negative logic after acquiring the data bit from the data line a 10 microsecond react pulse is required to reset the interrupt flag.

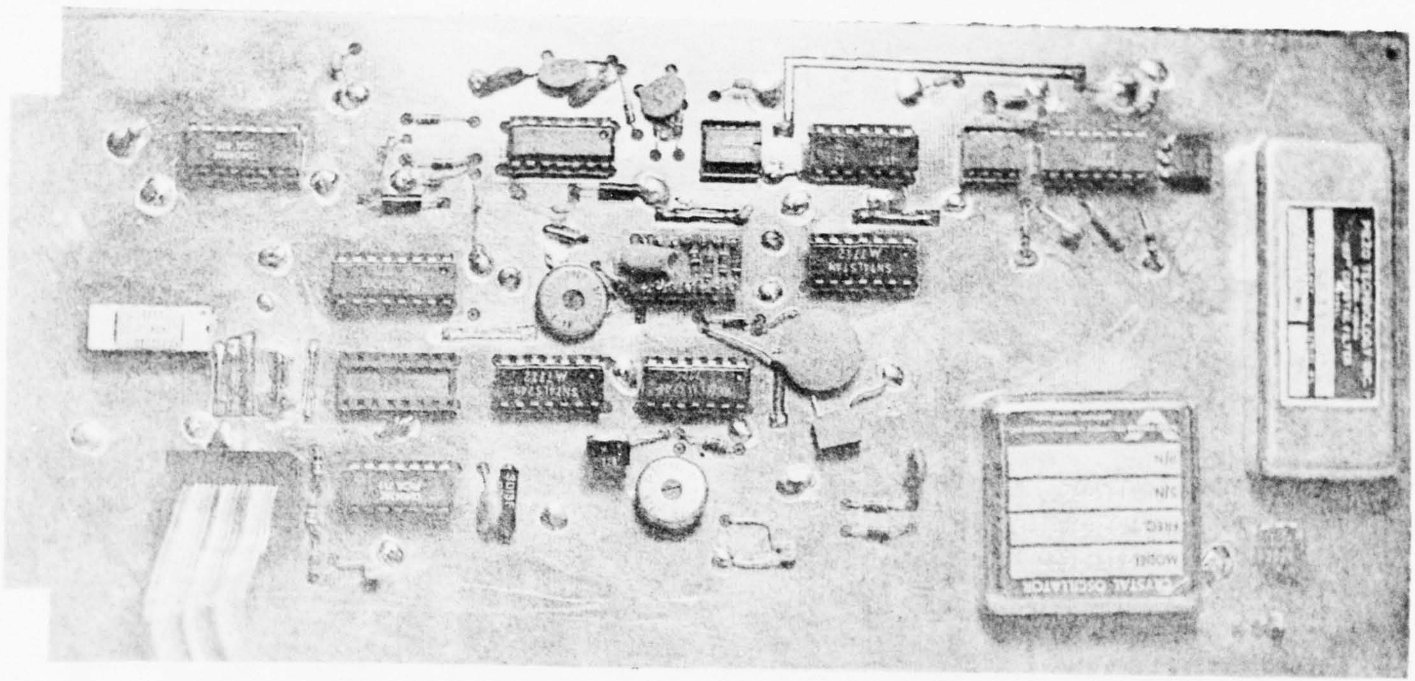


Figure B-1. DEMODULATOR CARRIER ACQUISITION CARD

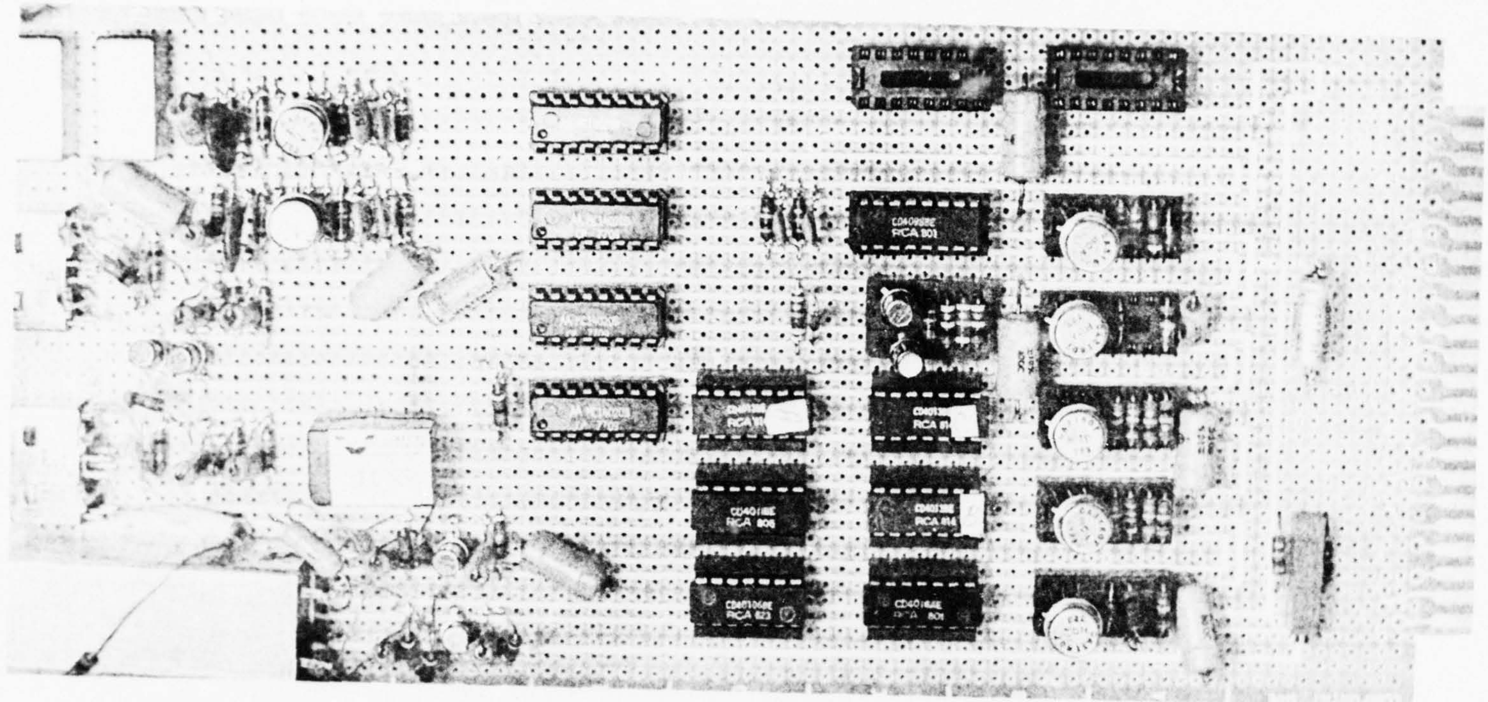


Figure B-2. DEMODULATOR DIGITAL CLOCK PHASE SHIFT, BIT SYNCHRONIZER, AND FREQUENCY DIFFERENCE MEASUREMENT FOR CARRIER SEARCH

LIST OF TABLES AND FIGURES

APPENDIX C

TABLE I. REGISTER ASSIGNMENT

INTERNAL CPU REGISTER USE FOR RR/DCP

R0	-	
R1	-	
R2	-	STACK POINTER
R(3)	-	PROGRAM COUNTER
R(4)*	-	PROGRAM COUNTER FOR CALL ROUTINE
R(5)*	-	PROGRAM COUNTER FOR RETURN ROUTINE
R(6)*	-	POINTER TO RETURN LOCATION AND ARGUMENTS PASSED BY THE CALLING PROGRAM
R7	-	R7.1 (cycles since last transmission) R7.0 (transmission at current rate)
R8	-	RAM POINTER (R8.1 must be left at 8C)
R9	-	MULTIPLE USE
RA	-	" "
RB	-	" "
RC	-	" "
RD	-	" "
RE	-	" "
RF	-	" "

*NOTE: THE STANDARD CALL-RETURN TECHNIQUE IS USED IN ALL RR/DCP SOFTWARE.

Table II. MEMORY MAP

MEMORY MAP - ROM

LOCATION	USE
0000	EXECUTIVE PROGRAM
.	
.	
.	
0145	
158	UTILITY ROUTINES
.	
.	
.	
1F2	
0200	TRANSMITTER SUBROUTINE
.	
.	
.	
02C0	
02C1	FREQUENCY TO DIGITAL CONVERSION ROUTINE
.	
.	
.	
02EB	
02EC	RANDOM # GENERATOR SUBROUTINE
.	
0300	
0302	ENCODE DATA FOR TRANSMITTER SUB.
.	
.	
.	
034A	
034D	UPDATE TRANSMISSION RATES SUB.
.	
.	
.	
0390	
0393	CALCULATE STAGE RATE SUB.
.	
.	
03EE	
03F2	GENERAL CALCULATION SUBROUTINE
.	
.	
.	
042E	

Table II. MEMORY MAP (CONT.)

LOCATION	USE
0431 . . . 0444	DELAY SUBROUTINE
0447 . . . 0460	READ TIPPING BUCKET INTERFACE SUBROUTINE
0447 . . . 0488	CONTROL INSTRUMENT INTERFACE SUBROUTINE
0491 : . . 04C1	PART OF DECIMAL DISPLAY PROGRAM
04C3 . . . 04F3	UTILITY ROUTINES CONT'D.
0500 . . . 05FE	DECIMAL DISPLAY PROGRAM
C000 . . C3FF	RCA MATH ROM
8000 . . 81FF	RCA UTILITY ROM UT5

Table II. MEMORY MAP (CONT.)

MEMORY MAP - RAM

LOCATION	USE
8C00	RAM FOR UT5
.	
.	
8C1F	
8C20	FREQUENCY OF SYSTEM VOLTAGE (Hz)
8C22	FREQUENCY OF GROUND VOLTAGE (Hz)
8C24	FREQUENCY OF STAGE (α1) INPUT (Hz)
8C26	FREQUENCY OF PRECIP (β2) INPUT (Hz)
8C28	STAGE (P1) MINIMUM VALUE (Ft x 100)
8C2A	PRECIP (P2) MINIMUM VALUE (in x 100)
8C2C	CURRENT STAGE (P1) (Ft x 100)
8C2E	STAGE (P1) 8 min ago (Ft x 100)
8C30	STAGE (P1) 16 min ago (Ft x 100)
8C32	CURRENT PRECIP (P2) (in x 100) (0-4000)
8C34	PRECIP (P2) 8 min ago *in x 100) (0-1000)
8C36	R1, BASE TRANSMISSION RATE (T/Hr x 100)
8C38	R2, ALERT TRANSMISSION RATE (T/Hr x 100)
8C3A	R3, FLOOD TRANSMISSION RATE (T/Hr x 100)
8C3C	A, STAGE (P1) SLOPE FACTOR (0-100)
8C3E	B, PRECIP (P2) SLOPE FACTOR (0-100)
8C40	ALERT LEVEL (Ft x 100)
8C42	FLOOD LEVEL (Ft x 100)
8C44	RANDOM #
8C46	TRANSMITTER RF FOREWARD POWER (v x 100)
8C48	TRANSMITTER RF REFLECTED POWER (v x 100)
8C4A	CURRENT TRANSMISSION RATE
8C4B	BACKUP RATE
8C4C	BACKUP RATE
8C4D	RATE COMPUTED FROM P1
8C4E	RATE COMPUTED FROM P2
8C4F	NOT USED
8C50	TEST
8C51	TEST
8C52	PARAMETER 2 SELECT: BUCKET OR FREQUENCY
8C53	
8C54	
8C55	
8C56	
8C57	NOT USED
8C58	NOT USED
8C59	
8C5A	USED AS SCRATCH PAD AND FOR BINARY DECIMAL CONVERSION
.	
.	
8C61	

Table II. MEMORY MAP (CONT.)

LOCATION	USE
8C62	PLATFORM ID
.	
.	
.	
8C65	
8C66	RAW DATA THAT WILL BE ENCODED
.	
.	
.	
8C69	
8C6A	ENCODED DATA THAT WILL BE TRANSMITTED
.	
.	
8C6D	
.	

Table III. EPROM CHIP 1

```
 ?MO 100
0000   C081 08FF FFF8 8CB8   F800 A7F8 EEB7 F850;
0010   A8F8 0158 18F8 0058   F844 A8F8 0058 18F8;
0020   0558 F84A A8F8 FF58   1858 1858 F868 A8F8;
0030   0058 1858 3050 FFFF   FFFF FFFF FFFF FFFF;
0040   FFFF FFFF FFFF FFFF   FFFF FFFF FFFF FFFF;
0050   F851 A808 3AD4 F801   58D4 C249 8C2E D4C2;
0060   5BD4 C24D D4C2 5BD4   C249 8C2C D4C2 5BD4;
0070   0465 E365 00D4 03F2   2422 0FA0 6628 2CF8;
0080   52A8 083A 91D4 03F2   2622 03E8 682A 3230;
0090   9BD4 C249 8C68 D4C2   578C 32F8 54A8 0832;
00A0   A5F8 0058 D5F8 50A8   0832 C1F8 0058 D4C2;
00B0   498C 2CD4 C25B D4C2   5BD4 C249 8C32 D4C2;
00C0   5BD4 0393 2C30 3C4D   D403 B132 343E 4ED4;
00D0   034D 30DC F800 58D4   0431 009A E8F8 4AA8;
00E0   97FC 01B7 F7CB 0139   F800 B717 D402 EC9F;
00F0   FA0F BFD4 0435 D404   65D4 03F2 2422 0FA0
.?M100 100
0100   6628 5AF8 52A8 08CA   0114 D403 F226 2203;
0110   E868 2A5A D403 02D4   0200 0604 F853 A808;
0120   3226 F800 58D5 D4C2   498C 449F FA0F BFD4;
0130   C00D 0FFF D404 3530   3ED4 0431 10D4 D404;
0140   3110 E3C0 0050 FFFF   FFFF FFFF FFFF FFFF;
0150   FFFF FFFF FFFF FFFF   F801 B3F8 96A3 D3FF;
0160   F804 B3F8 FEA3 D3FF   F804 B3F8 D6A3 D3FF;
0170   F801 B3F8 C0A3 D3FF   F804 B3F8 C3A3 D3FF;
0180   F801 B3F8 88A3 D3FF   F88C B8F8 53A8 F801;
0190   58D4 0114 30BD D402   C1BE 2ED4 02C1 BF30;
01A0   D404 65D4 03F2 2E22   03E8 465F 5FD4 03F2;
01B0   3022 03E8 485F 5FF8   46A8 E365 00C0 0503;
01C0   F852 A8F8 8CB8 0832   E0F8 61AF 98BF EFF8;
01D0   0173 F880 7373 7373   7373 5FD4 816C 30DB;
01E0   D404 65D4 03F2 2226   03E8 6632 2AF8 2AA8;
01F0   C005 03FF FFFF FFFF   FFFF FFFF FFFF FFFF
.?
```

Table IV. EPROM CHIP 2

```
 ^C
.?M200 100
0200  E365 88D4 02AF 192D  E365 98C4 C4C4 F88C;
0210  B8C4 C4D4 02AF 324E  7AC4 341A 3C1C C4C4;
0220  D402 AF00 013C 257B  46AD F808 ACF8 AAAF;
0230  D402 7800 2D8D 3A2D  F822 AFD4 0278 00F8;
0240  EBAF D402 7800 F861  A8F8 03AD 18D4 0276;
0250  012D 8D3A 4C18 F807  ACD4 0276 01F3 69A8;
0260  46AD 18D4 0276 002D  8D3A 62F8 04AF D402;
0270  7800 E365 00D5 08AF  E6F8 00F1 3282 8FFE;
0280  3084 8FF6 AF3B 943C  877A D402 AF00 013C;
0290  8F7B 309F 3C94 7BD4  02AF 0001 3C9C 7A2C;
02A0  8C3A A8F8 08AC 16D5  D402 AF00 0130 7846;
02B0  BE46 AE2E 9E3A BC8E  32C0 30B3 8E8E 30B3;
02C0  D5E6 6546 A8F8 00AF  BFAE F84C BDF8 8FAD;
02D0  3DE0 8E3A DD1F 1E2D  9D3A D030 E68E 30D7;
02E0  F800 AEAE 30D7 9F58  188F 58D5 D4C2 498C;
02F0  44D4 C04F 0300 9FFA  7FBF D4C2 578C 44D5
.?M300 100
0300  0C35 98B9 F86A A9F8  6AA8 F802 AD28 08FA;
0310  3FBF D403 2A08 7E7E  7EFA 0352 2808 FEFE;
0320  F1BF D403 2A2D 8D3A  0DD5 F800 AFF8 06AC;
0330  9F59 9FF6 3B37 1FBF  2C8C 3A32 8FF6 3345;
0340  09F9 4030 4809 F9C0  5919 D5FE FEE8 87FF;
0350  043B 60F8 4BA8 72AF  F028 738F 73F8 00A7;
0360  F84D A872 BFF7 336C  F0AF 3070 9FAF F0BF;
0370  F84A A89F F733 7F9F  58F8 00A7 1830 869F;
0380  18F7 3386 9F58 8FF7  338C 8F58 189F 58E2;
0390  D5FF FFF8 36A8 D4C2  498C 2CD4 C262 8C40;
03A0  3BB4 F838 A8D4 C262  8C42 3BB4 F83A A830;
03B0  B4F8 36A8 988D 46AD  D4C2 4D46 ADD4 C031;
03C0  D403 E146 ADD4 C053  88AD D4C1 D5D4 C257;
03D0  8C5A D4C2 5205 DCD4  C0A1 8C5A 46AD 8F5D;
03E0  D59F FE3B EE9F FBFF  BF8F FBFF AF1F D5FD;
03F0  FDFF D4C2 498C 20D4  C02D 8C22 D4C2 578C
.
```

Table V. EPROM CHIP 3

```
?M400 100
0400   5C46 ADD4 C24D 46AD  D4C0 31D4 C257 8C5A;
0410   46BF 46AF D4C0 4F8C  5AF8 5CAD D4C0 B746;
0420   ADD4 C25B 46AD D4C1  D546 ADD4 C25B D500;
0430   0046 BF46 AFD4 02AF  0007 2F9F 3A42 8F3A;
0440   35D5 9F3A 35D4 C249  8C68 D4C1 EB01 00F8;
0450   FFAD E83F 5D61 2F8D  325D 2D30 5362 D4C2;
0460   578C 68D5 FFE3 6528  D402 AF19 2DD4 02C1;
0470   2822 D402 C129 20D4  02C1 2A24 F852 A808;
0480   3A89 D402 C12B 2630  8CD4 0445 D5FF FFFF;
0490   FF3E A894 BAF8 22AA  6C4A F332 A48A FF36;
04A0   33A9 3099 8AFF 23AA  D5F8 00BA D5F8 61AF;
04B0   EFF8 1073 7373 7373  F880 7373 F80B 73C0;
04C0   05D1 00F8 8CB8 F854  A8F8 0158 D400 6FF8;
04D0   20A8 C005 03FF D404  65D4 03F2 2224 0FA0;
04E0   662C 28F8 28A8 C005  03FF FFFF FFFF FFFF;
04F0   FFFF FFFF FFFF FFFF  FFFF FFFF FFFF 36FE
.?M500 100
0500   F820 A8F8 8CB8 BFEF  F861 AF88 FA0F F910;
0510   7388 F6F6 F6F6 F910  73F8 0C73 F808 73F8;
0520   8073 7373 F80A 5FF8  5AAF D481 6CF8 01BA;
0530   D404 91F8 61AF 9A32  2DF6 3227 8AFB 1232;
0540   530F 2F5F 1F8A F910  5FF8 5AAF D481 6C36;
0550   4C30 272F 4FFE FEFE  FE52 0FFA 0FF1 A836;
0560   5FF8 00A7 88AD 98BD  D4C2 4DD4 C30A 8C5C;
0570   06D4 C252 8C5C 0F52  F880 5F2F 5F2F 025F;
0580   D481 6CF8 01BA D404  919A 3283 F632 808A;
0590   FB12 32DB 8AFB 103A  A287 3A9E 1738 2787;
05A0   CA04 AD87 325F 8AFB  0B3A AF8A 5F30 D18A;
05B0   FB0D 3AB8 8A5F 30D1  F804 ADF8 5EAF 0F2F;
05C0   5F2D 8D32 C91F 1F30  BE1F 8AF9 105F F85D;
05D0   AFF8 5AAF D481 6C36  D430 80F8 5AAF 0F1F;
05E0   1F5F D4C2 9F8C 5C06  98BD 88AD D4C2 5B18;
05F0   1836 F130 03FF FFFF  FFFF FFFF FFFF FFFF
```

Table VI. RCA MATH ROM

```
?MC000 100
C000  9EAC 9FBE 8EBF 8FAE  9FAF 8CBF D586 AD96;
C010  BD16 1630 1946 BD46  ADED 9FF3 521D 8FF5;
C020  AF2D 9F75 BF02 FE3B  2C9F F3FE D546 BD46;
C030  ADED 9FF6 529F F3FA  80E2 F452 1DED 8FF7;
C040  AF2D 9F77 BFE2 F0FE  3B4E 529F F3FE D546;
C050  BD46 ADED 9FF3 FA80  BCF8 10AC F800 BEAE;
C060  2C9F F6BF 8F76 AF9E  3B76 1D8C 3A79 8EF7;
C070  AE2D 9E77 BE9C FE30  838E F4AE 2D9E 74BE;
C080  CFF0 FE9E 76BE 8E76  AE3B 8F9F F980 BF8C;
C090  3A60 9FFE 8EC7 FBFF  3A9E 9EC7 FBFF FCFF;
C0A0  D546 BD46 ADED 9FFE  F800 C7F8 FFBE AE4D;
C0B0  F12D FD00 3BB7 D59E  BC8E ACFE AE9E 7EBE;
C0C0  9FFE 33CD 8C3A CE9C  FB40 32D7 381E 9CFA;
C0D0  C0FD 00FE C3C1 569C  EDF3 FE1D 8E33 E6F7;
C0E0  AE2D 9E77 30EB F4AE  2D9E 74BE 9CFE CBC0;
C0F0  FA9E FBFF BE8E FBFF  AE1E 9EC2 C103 FE33
.?MC100 100
C100  5B30 548E FCFE 3356  FBFF 3A39 9CFA 8032;
C110  54F4 3356 1D8F F4AE  2D9F 74BE 1DF0 F62D;
C120  9EC7 FC80 BEFE 9CFA  803A 2F3B 5430 5B33;
C130  569E 3A5B 3E32 5430  5B9C F3FE 3314 9CFE;
C140  3B54 1DF0 2DF6 8F3A  5B9F 3350 3254 305B;
C150  FB80 3A5B FF00 9CBE  8CAE D59C BE8C AE9E;
C160  FEF8 90C7 F850 AC8E  FEAE 9E7E BE8F FEAF;
C170  9F7E BF3B 761E ED8C  F3FE 1D8E 3B85 F7AE;
C180  2D9E 7730 8AF4 AE2D  9E74 BE2C 8CFA 7F3B;
C190  941F F980 ACFA 3F3A  6733 B038 1FF3 FE1D;
C1A0  8E33 AAF4 AE2D 9E74  30AF F7AE 2D9E 77BE;
C1B0  9E3A B68E 32C1 8CFE  FE9E CFFB 80FC 803B;
C1C0  9CF0 FE3B D08F FBFF  AF9F FBFF BF1F FC00;
C1D0  D546 BD46 ADED 9FF3  FB80 521D 8FF4 AF2D;
C1E0  9F74 BF02 FE3B EA9F  F3FE D586 AD96 BD16;
C1F0  1630 D592 BD82 AD1D  1D1D 30D5 92BD 82AD
.
```

Table VI. RCA MATH ROM (CONT.)

```
 ?MC200 100
C200   1D1D E20D 732D 0D73   9F5D 8F1D 5D2D D58D;
C210   E273 9D52 92BD 82AD   221D 1D1D 8E73 9E73;
C220   0D73 2D0D 739C 5D1D   8C5D D512 92BD 82AD;
C230   1D1D 1D1D 1D1D 4DBC   0DAC 2D42 5D1D 425D;
C240   42BE 42AE 42BD 02AD   D546 BD46 AD4D BF4D;
C250   AFD5 46BF 46AF D546   BD46 AD9F 5D1D 8F5D;
C260   1DD5 46BD 46AD ED9F   F3FA 803A 769F F73A;
C270   771D 8FF7 2D38 F4D5   1616 D59F FE9F 3A78;
C280   8F32 7A30 78FF 00C8   FC00 1292 BD82 AD1D;
C290   1D3B 984D BF0D AF2D   425D 1D02 5D1D D546;
C2A0   BA46 AA46 FF01 ABF8   00AF BF0A FB0D BB1A;
C2B0   E20A FA0F 528F F4AF   9F7C 00BF 33EF 2B8B;
C2C0   32F0 8FFE 739F 7E73   33ED F802 528F FEAF;
C2D0   9F7E BF33 ED02 32DC   FF01 30CC 129F F4BF;
C2E0   33EE 128F F4AF 9F7C   00BF 3BAF C812 12D5;
C2F0   9FFC 803A FC8F 3AFC   9BFC FFD5 33FB 9B3A
.?MC300 100
C300   098F FD00 AF9F 7D00   BFD5 46BA 46AA 46FF;
C310   01AB BBF8 0FAD 9FFE   F80B 3B29 8FFD 00AF;
C320   9F7D 00BF F80D C8F8   005A 8B32 321A 2B30;
C330   27E2 9BAB 8FFE AF9F   7EBF 0A7C 005A 8D3A;
C340   42D5 0A7E 5AFF 0A3B   4A5A 2A2B 8B3A 4233;
C350   412D 9B52 8AF4 AA9A   7C00 BA30 32D3 E296;
C360   7386 7393 B683 A646   B346 A330 5DD3 96B3;
C370   86A3 E212 72A6 F0B6   306D 0000 0000 0000;
C380   0000 0000 0000 0000   0000 0000 0000 0000;
C390   0000 0000 0000 0000   0000 0000 0000 0000;
C3A0   0000 0000 0000 0000   0000 0000 0000 0000;
C3B0   0000 0000 0000 0000   0000 0000 0000 0000;
C3C0   0000 0000 0000 0000   0000 0000 0000 0000;
C3D0   0000 0000 0000 0000   0000 0000 0000 0000;
C3E0   0000 0000 0000 0000   0000 0000 0000 0000;
C3F0   0000 0000 0000 0000   0000 0000 0000 0000
.
```

Table VII. RCA UT-5 ROM

```
.?M8000 100
8000   7100 0203 0405 0607  0809 0A0B 0C0D 0E0F;
8010   01F8 80B3 F8FE A3C0  810E F800 A794 BDF8;
8020   80AB E222 228B 5247  FA0F FC36 AD4D BB64;
8030   8CFA 0132 3F8B FA0F  3A44 9BFA BF30 458B;
8040   FAFC 323A 9B52 63D4  8147 E363 FFE2 87FF;
8050   063B 54D5 8BF6 ABFA  F33A 2330 4ED4 801A;
8060   365D D480 1A8C FA01  326D D480 D33E 62D4;
8070   801A 94BA F822 AA6C  4AF3 3283 8AFF 3633;
8080   5D30 788A FF23 AAFA  F03A 90D4 809E 305D;
8090   8AFA 0FFC 9AAA 93BA  4AA3 FAF0 F6FE 8CFA;
80A0   0132 E59F FEFE FEFE  528F F6F6 F6F6 F1BF;
80B0   8FFE FEFE FE52 8AF1  AFF8 00A7 9FF6 F6F6;
80C0   F657 179F FA0F 5717  8FF6 F6F6 F657 178F;
80D0   FA0F 574F AE2F F804  A78E F6F6 F6F6 5717;
80E0   8EFA 0F57 D58E FEFE  FEFE 528A F1AE 30D6;
80F0   9FB0 8FA0 E0D0 8E5F  1F38 1CC0 8102 F800
.?M8100 100
8100   BFAF D480 B9C0 805D  F800 B3F8 05A3 F881;
8110   B4B5 F8E4 A4F8 F4A5  F88C B2B7 F81F A2AC;
8120   E2D3 0A8E 8081 4E40  412E 2021 1E10 1106;
8130   0804 0209 010C 447D  C151 7852 425D 4050;
8140   4862 C661 C2CA FFF8  20AD 2D8D 3A4A D5F8;
8150   81B3 F858 A3C0 810E  F800 BFAF 1FF8 80A8;
8160   D480 B9D4 801A 2888  3A63 305C F880 AEF8;
8170   81BD 0FFA 803A 9722  228E 520F FA0F FC36;
8180   AD4D BE0F FA10 328C  9EFA BFBE 649E 5263;
8190   D481 47E3 63FF E21F  8EF6 AE3A 722F 2F2F;
81A0   2F2F 2F2F 2FD5 F88C  BFF8 00AF 9AF6 F6F6;
81B0   F65F 1F9A FA0F 5F1F  8AF6 F6F6 F65F 1F8A;
81C0   FA0F 5F1F 9BF6 F6F6  F65F 1F9B FA0F 5F1F;
81D0   8BF6 F6F6 F65F 1F8B  FA0F 5FF8 00AF D481;
81E0   6CD5 00D3 E296 7386  7393 B683 A646 B346;
81F0   A330 E3D3 96B3 86A3  E212 72A6 F0B6 30F3
```

Table VIII. RAM

```
 ?M8C00 100
8C00   0000 0000 0C00 0000  0000 0000 0000 0000;
8C10   0000 0000 0000 0000  0000 7102 4301 04C7;
8C20   1930 0000 13E3 14FA  0000 0000 0C56 0C56;
8C30   0C56 0341 0341 0000  0000 0000 0000 0000;
8C40   0000 0000 3D09 0000  0000 DCDC DCDC DC00;
8C50   0001 0000 0000 0000  0000 0340 1930 000C;
8C60   0010 0000 0000 0C56  0340 40CD D6F1 0000;
8C70   0000 0000 0000 0000  0000 0000 0000 0000;
8C80   0000 0000 0000 0000  0000 0000 0000 0000;
8C90   0000 0000 0000 0000  0000 0000 0000 0000;
8CA0   0000 0000 0000 0000  0000 0000 0000 0000;
8CB0   0000 0000 0000 0000  0000 0000 0000 0000;
8CC0   0000 0000 0000 0000  0000 0000 0000 0000;
8CD0   0000 0000 0000 0000  0000 0000 0000 0000;
8CE0   0000 0000 0000 0000  0000 0000 0000 0000;
8CF0   0000 0000 0000 0000  0000 0000 0000 0000
.
```

Figure C1

EXECUTIVE PROGRAM FLOWCHART

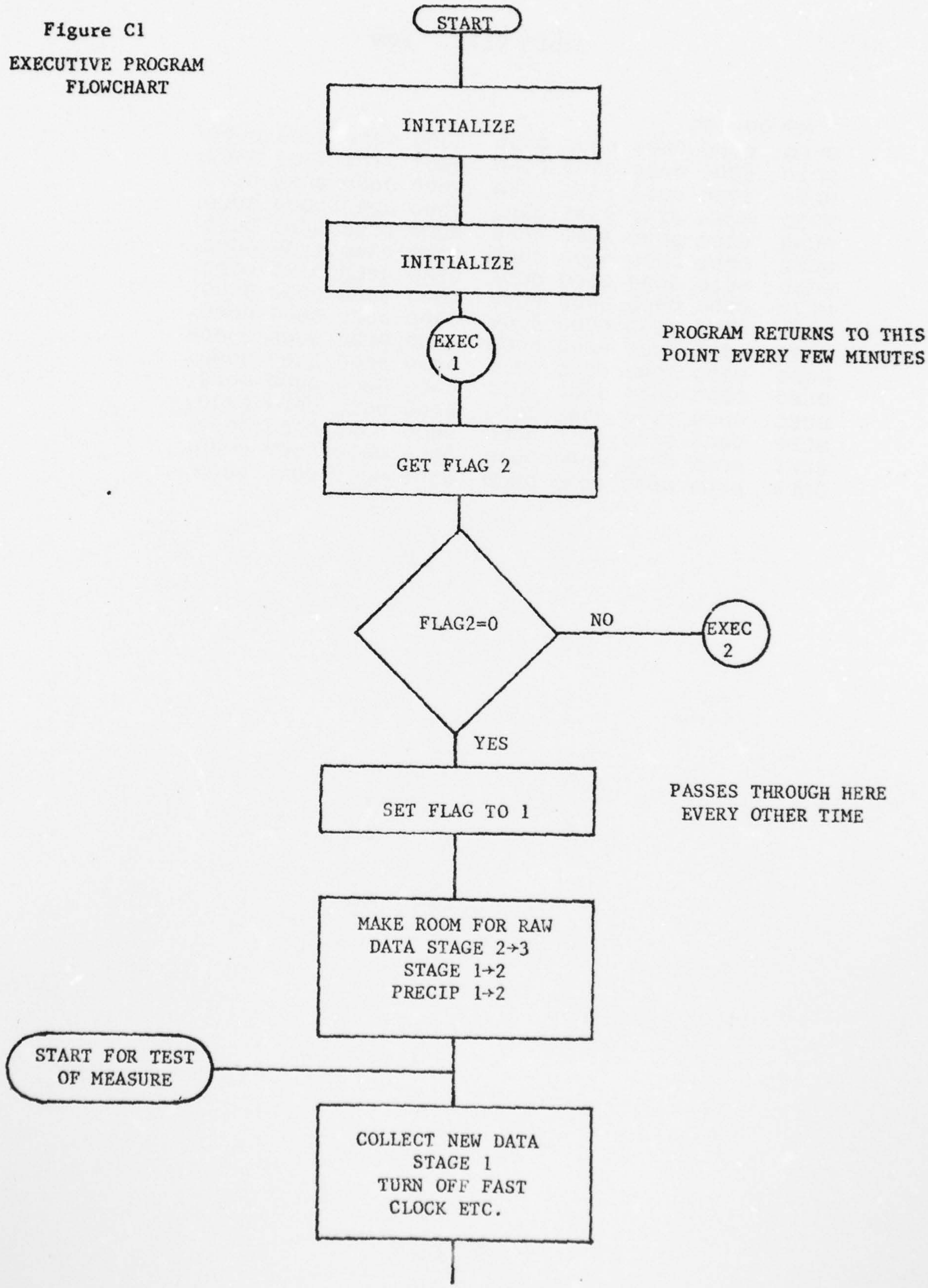


Figure C1
EXECUTIVE PROGRAM
FLOWCHART
(CONT'D)

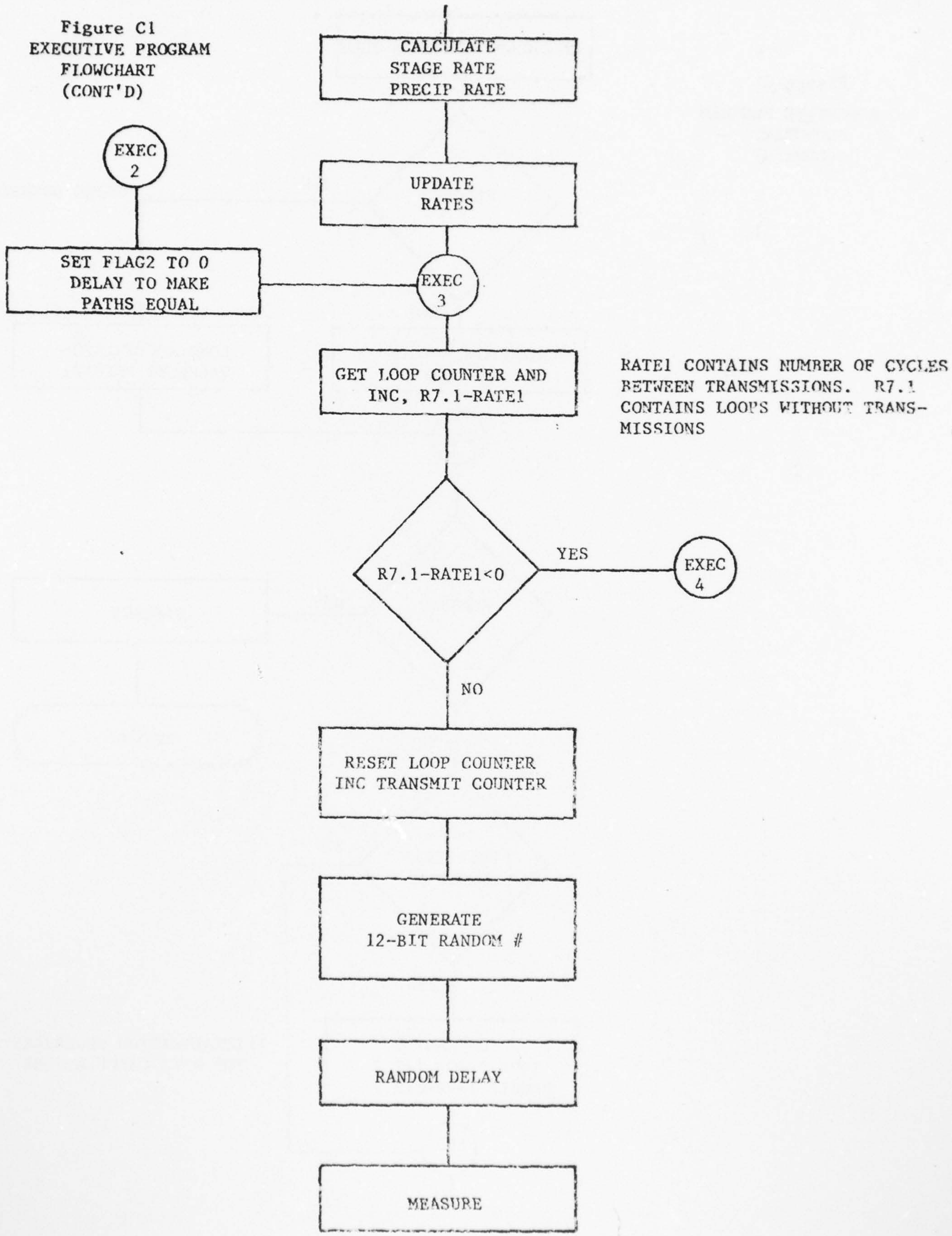


Figure C1

EXECUTIVE PROGRAM
FLOWCHART
(CONT'D)

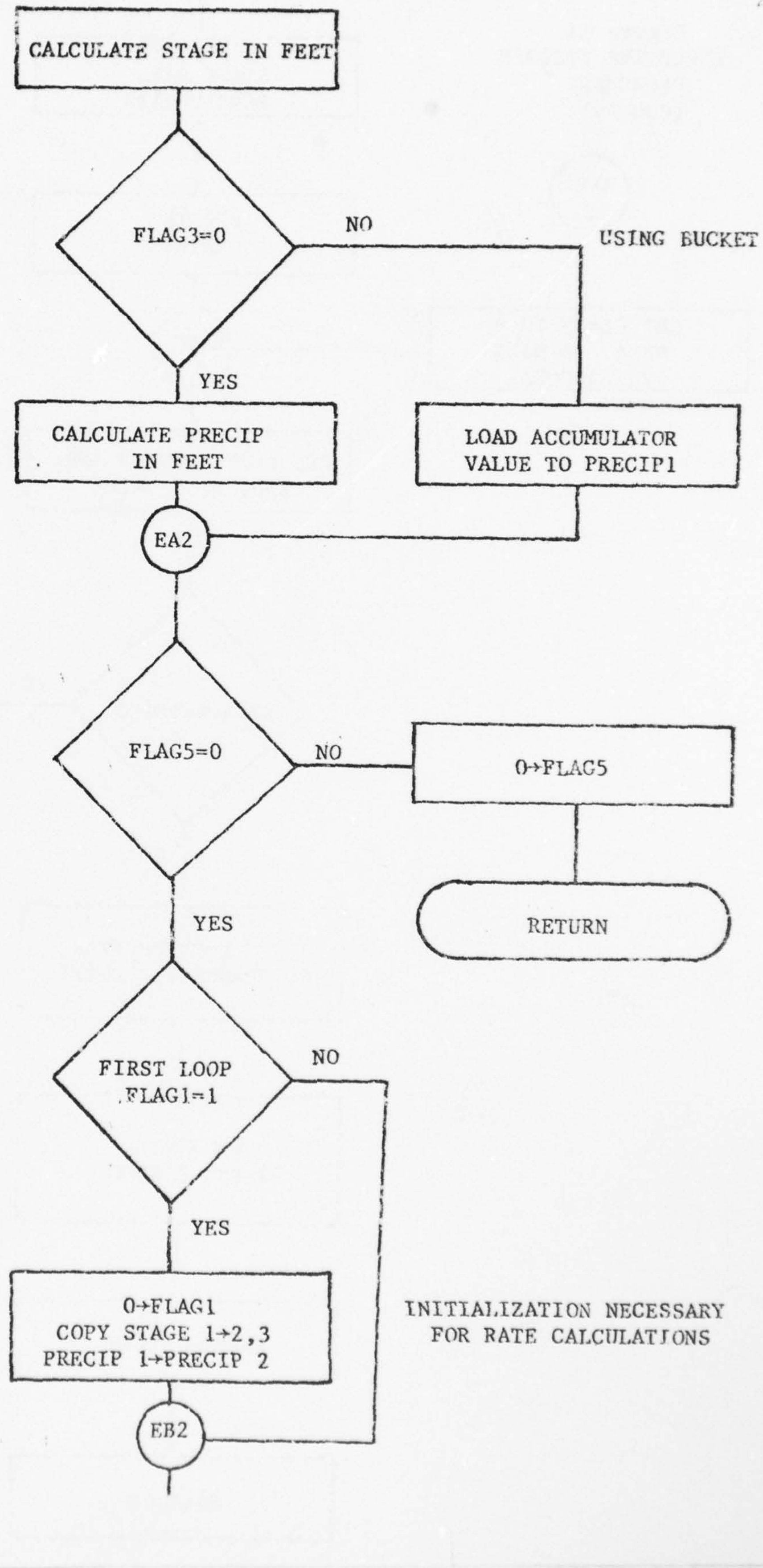
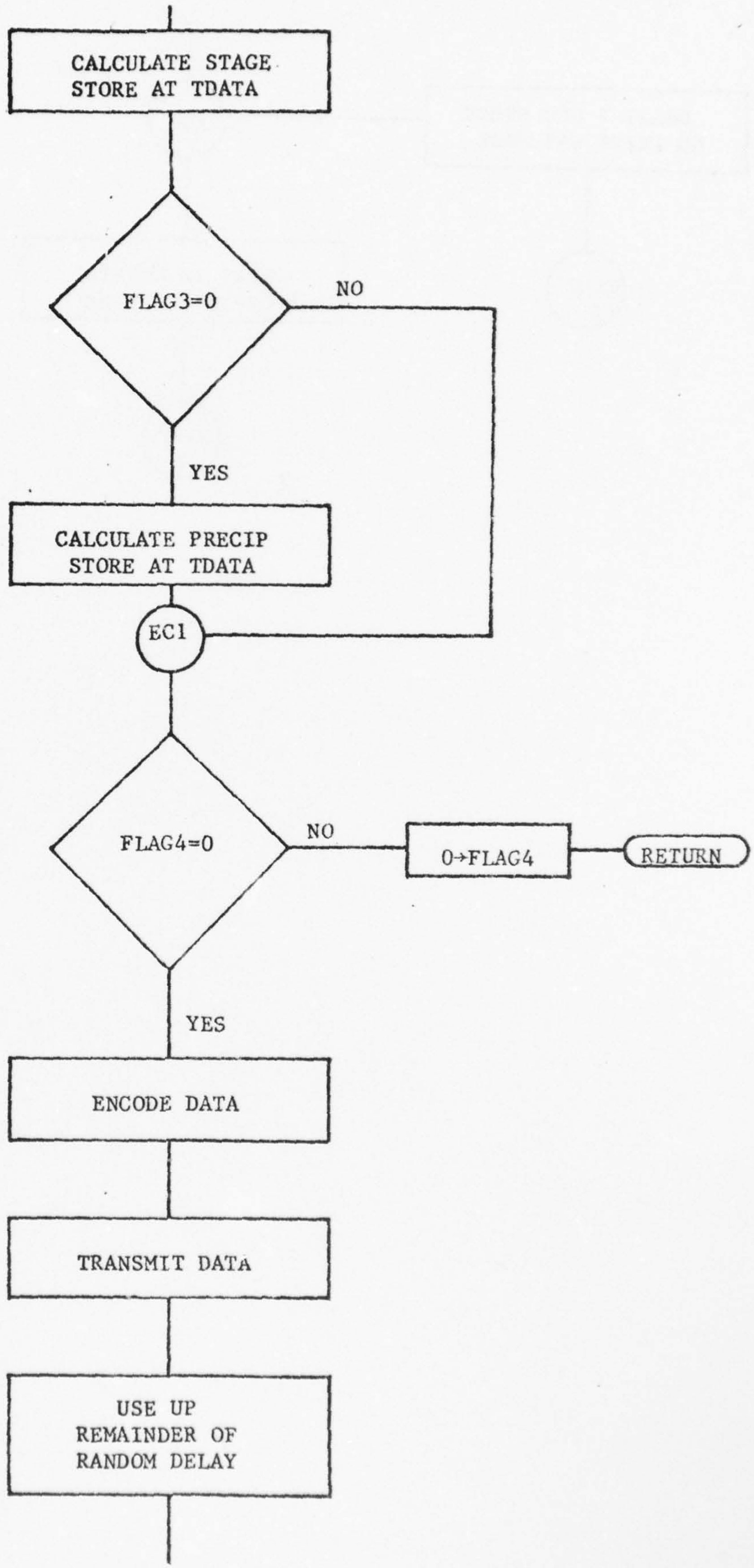


Figure C1

EXECUTIVE PROGRAM FLOWCHART (CONT'D)



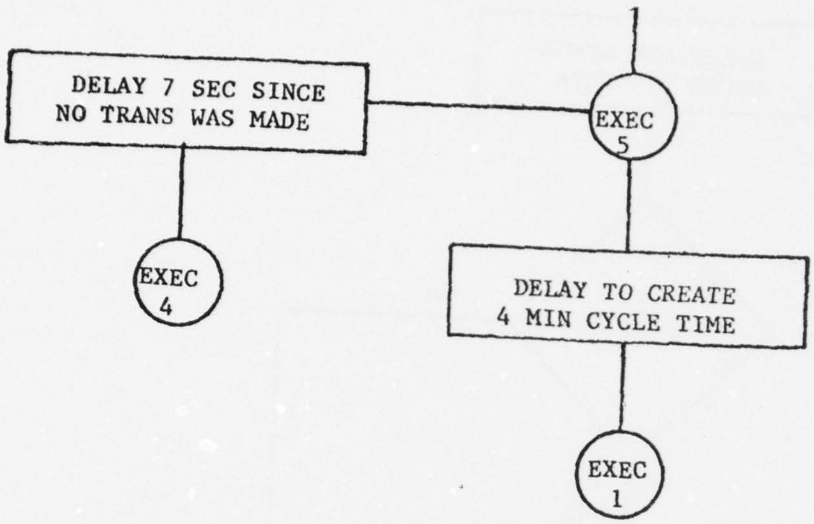


Figure C1

EXECUTIVE PROGRAM
FLOWCHART
(CONT'D)

AD-A067 290 SUTRON CORP ARLINGTON VA F/G 17/2.1

DEMONSTRATION OF ADAPTIVE RANDOM REPORTING GOES DATA COLLECTION--ETC(U)

JAN 79 D M PREBLE DACW33-78-C-0176

UNCLASSIFIED SCR-333-78-006 NL

2 OF 2

AD A067290

END

DATE FILMED

6--79

DDC

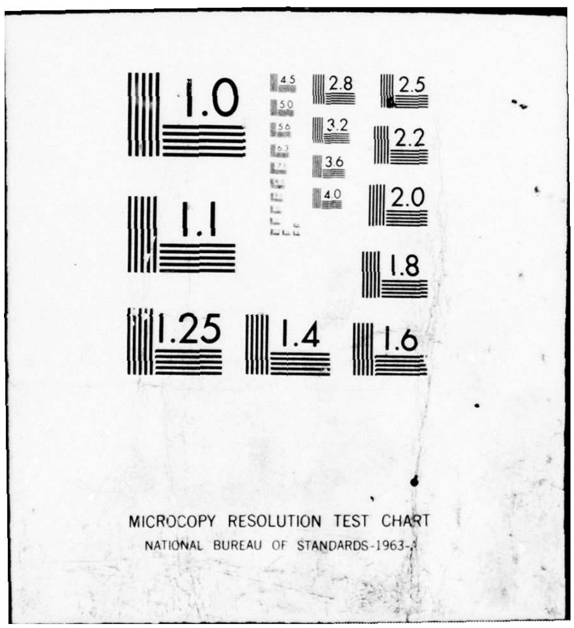
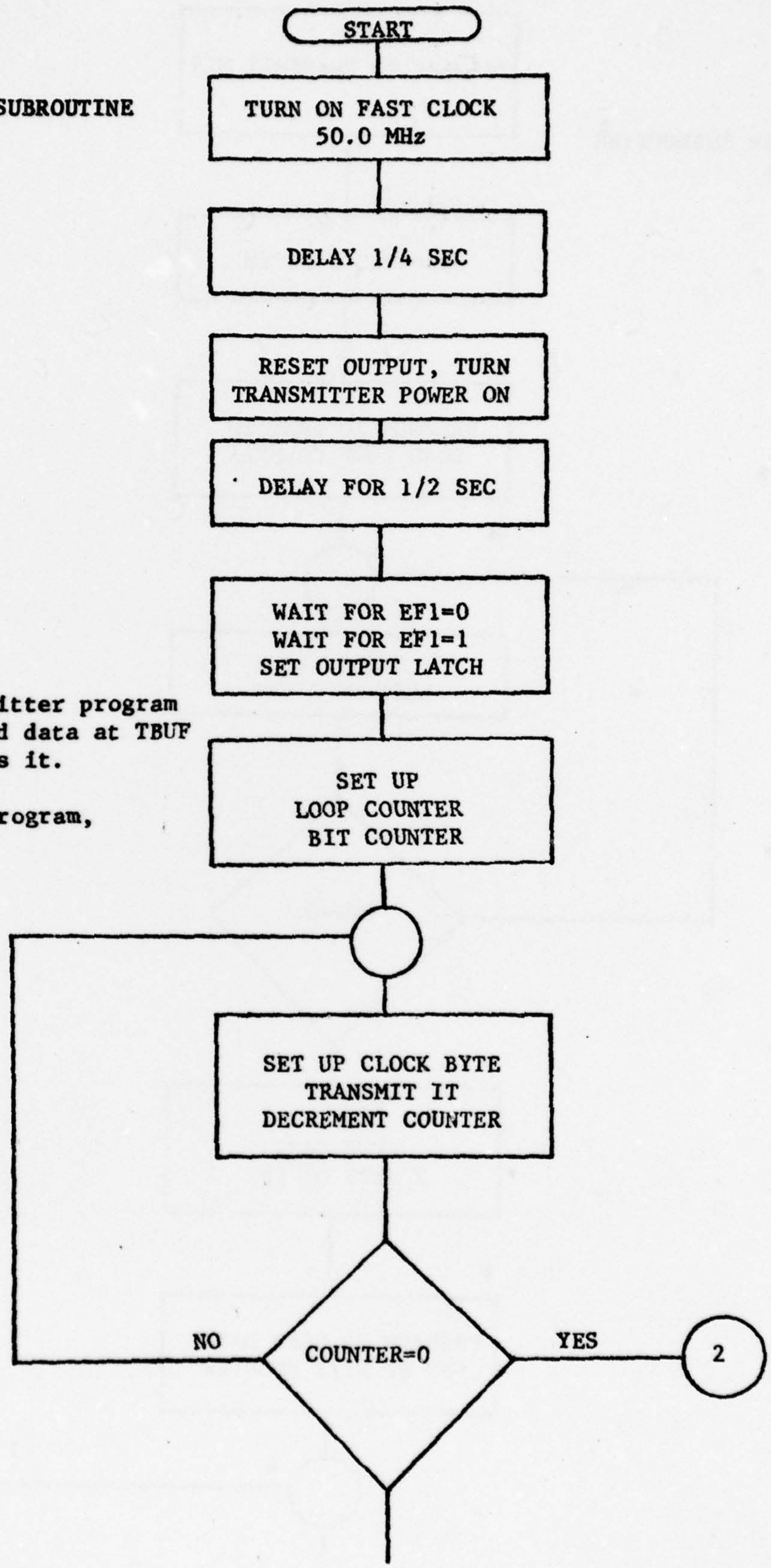

1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Figure C2

TRANSMITTER SUBROUTINE



Note: Transmitter program takes encoded data at TBUF and transmits it.

To use the program, execute:

SEP CALL
,A(GXMIT)
,#06
(6x8 clock bits)
,#04
(04 bytes data)

Figure C2

TRANSMITTER SUBROUTINE
(CONT'D)

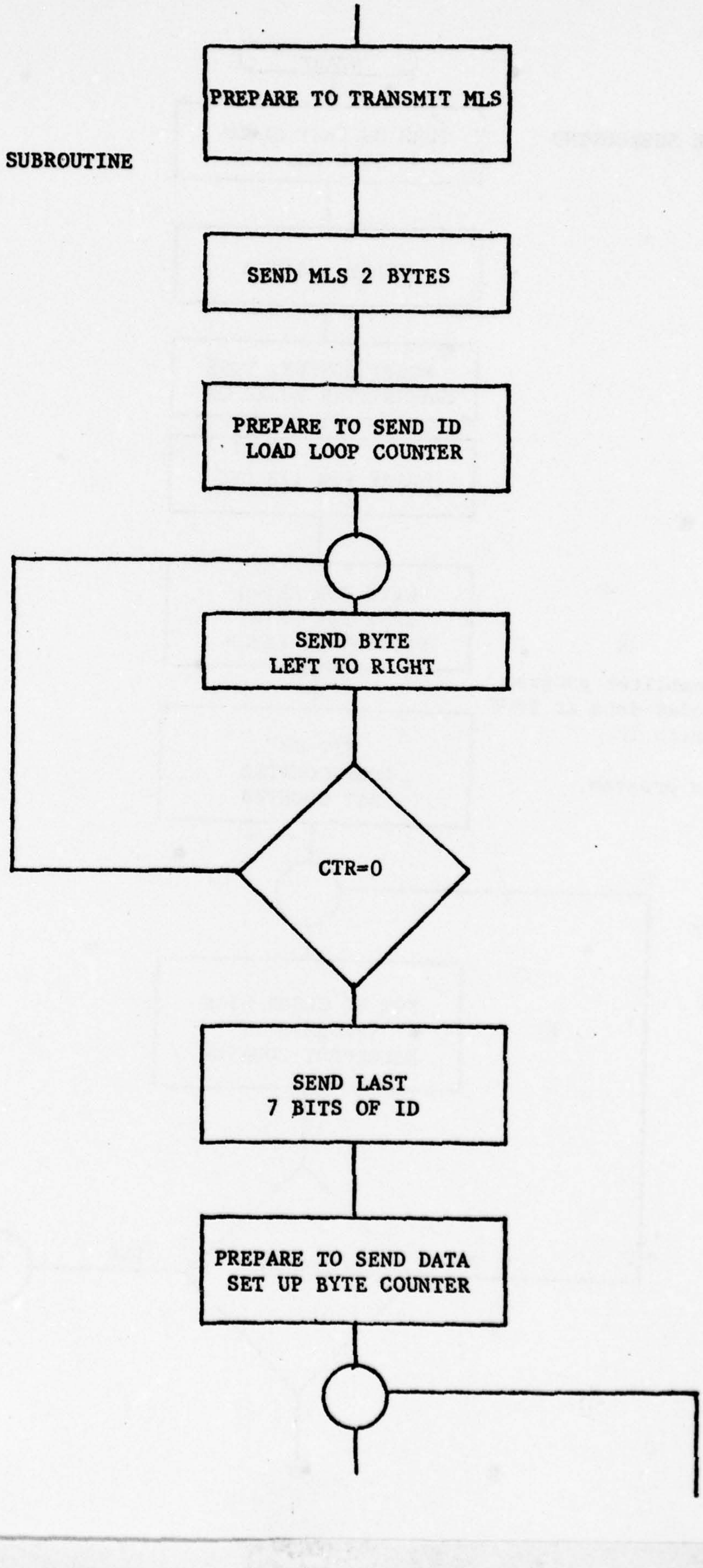
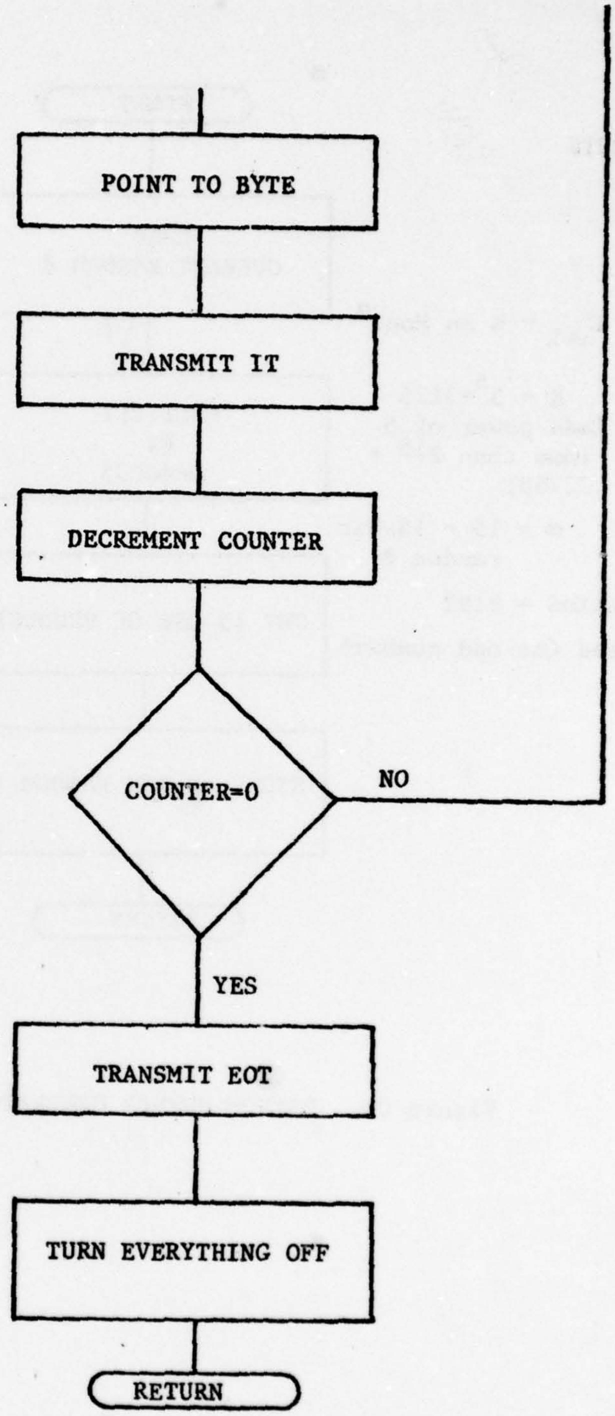


Figure C2
TRANSMITTER SUBROUTINE
(CONT'D)



TO USE EXECUTE
SEP CALL
,A(RND)

Equations: $R_{n+1} = K\ Rn\ Mod2^{n}$

$K = 5^5 = 3125$
(add power of 5
less than $2^{15} = 32768$)

$N = 15$ = 15-bit
random #

2^{N-2} = period = 8192

R_o = seed (an odd number)

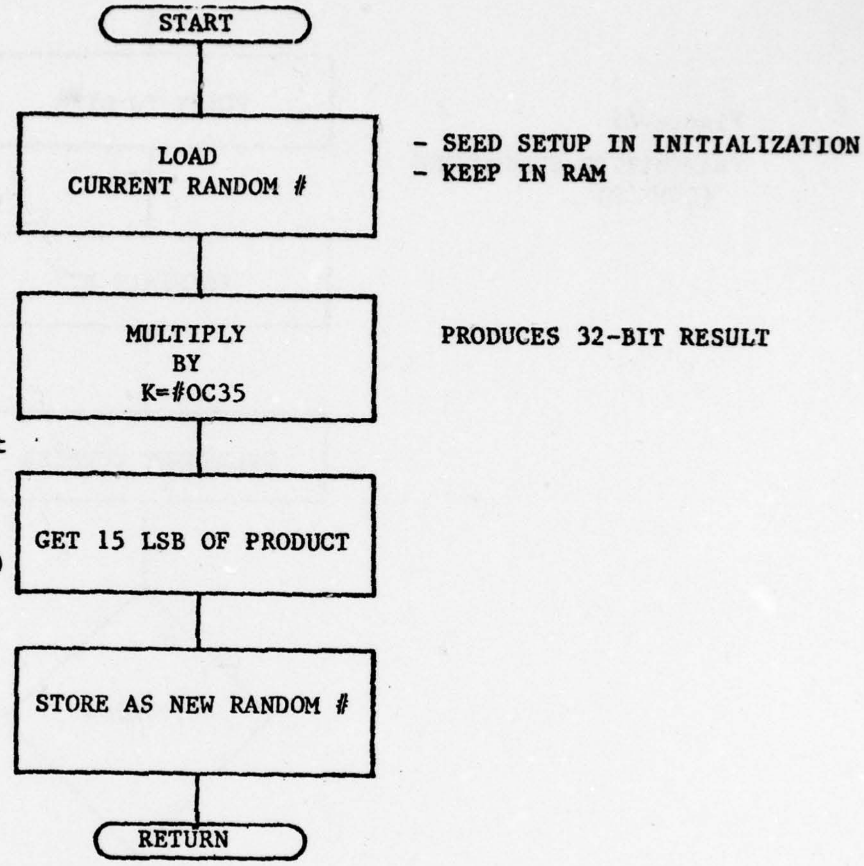


Figure C3. RANDOM NUMBER GENERATOR SUBROUTINE

Figure C4

FDC SUBROUTINE

TO USE, EXECUTE:

SEP CALL
,A(FDC)
,A.O(DEVICE)
,A.O(RAMSTORAGE)

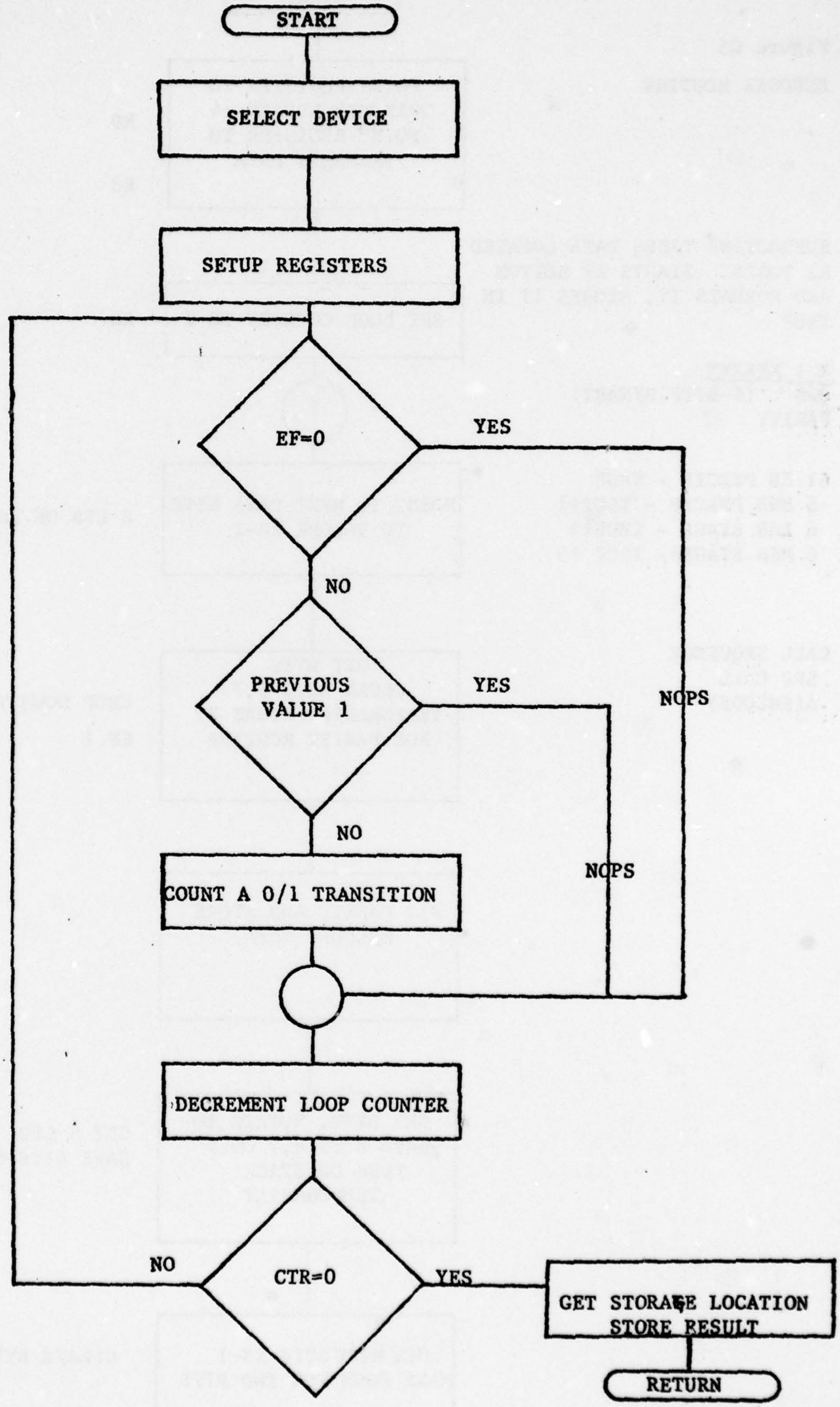


Figure C5

ENCODER ROUTINE

SUBROUTINE TAKES DATA LOCATED AT TDATA. STARTS AT BOTTOM AND FORMATS IT, STORES IT IN TBUF

X 1 XXXXXX
ODD (6-BITS BINARY)
PARITY

61 SB PRECIP - TBUF
6 MSB PRECIP - TBUT+1
6 LSB STAGE - TBUS+2
6 MSB STAGE - TBUF +3

CALL SEQUENCE
SEP CALL
A(ENCODE)

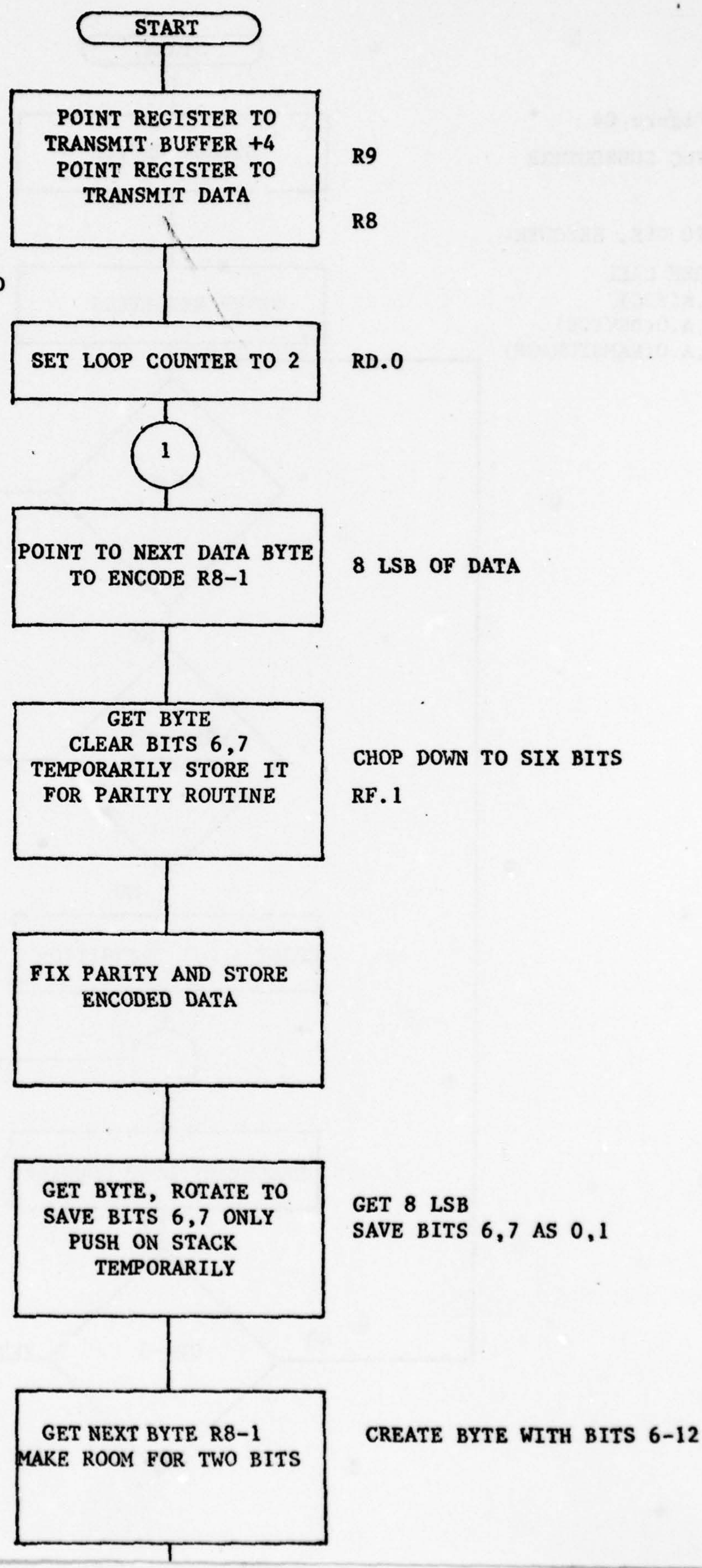


Figure C5

ENCODER ROUTINE
(CONT'D)

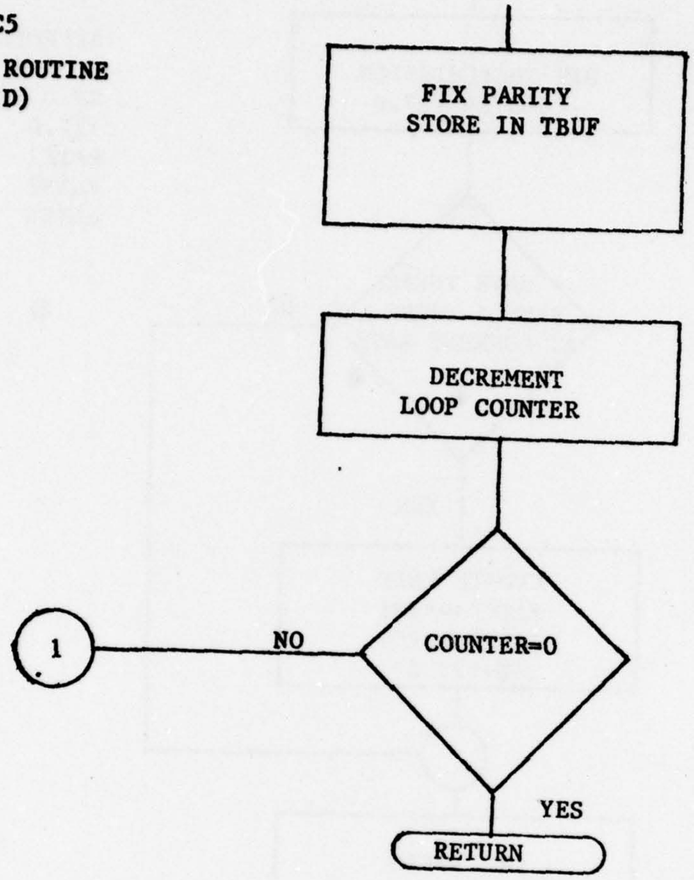


Figure C6

RATE UPDATE ROUTINE

<u>NOTE</u>: MIN VALUE GIVES MAX NUMBER OF TRANSMISSIONS

TO EXECUTE:

SEP CALL
,A(UPDATE)

AFFECTS
RF.1 MIN
RF.0 MAX
127.0
RATE1
RATE2
RATE3

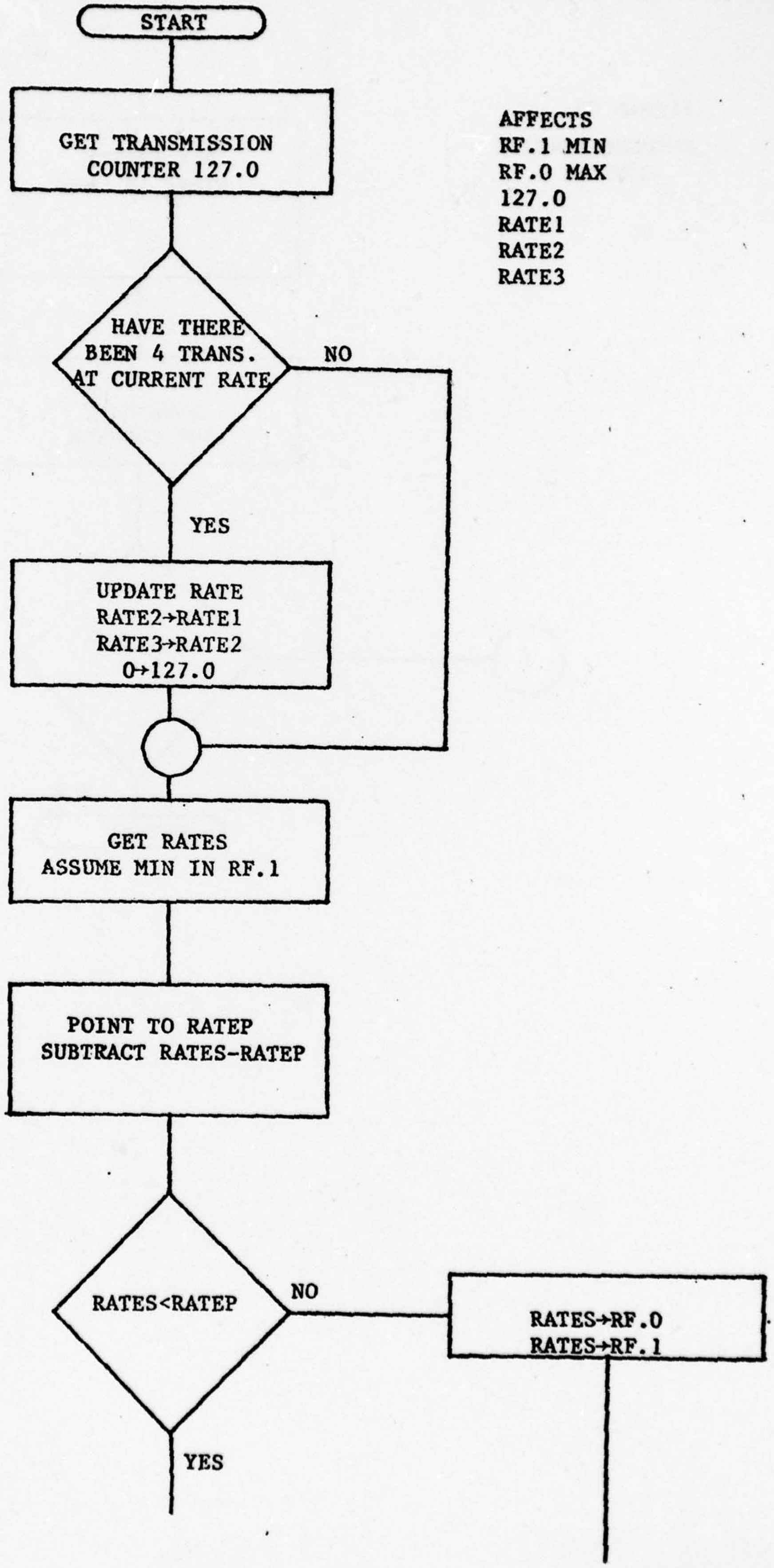


Figure C6

RATE ROUTINE
(CONT'D)

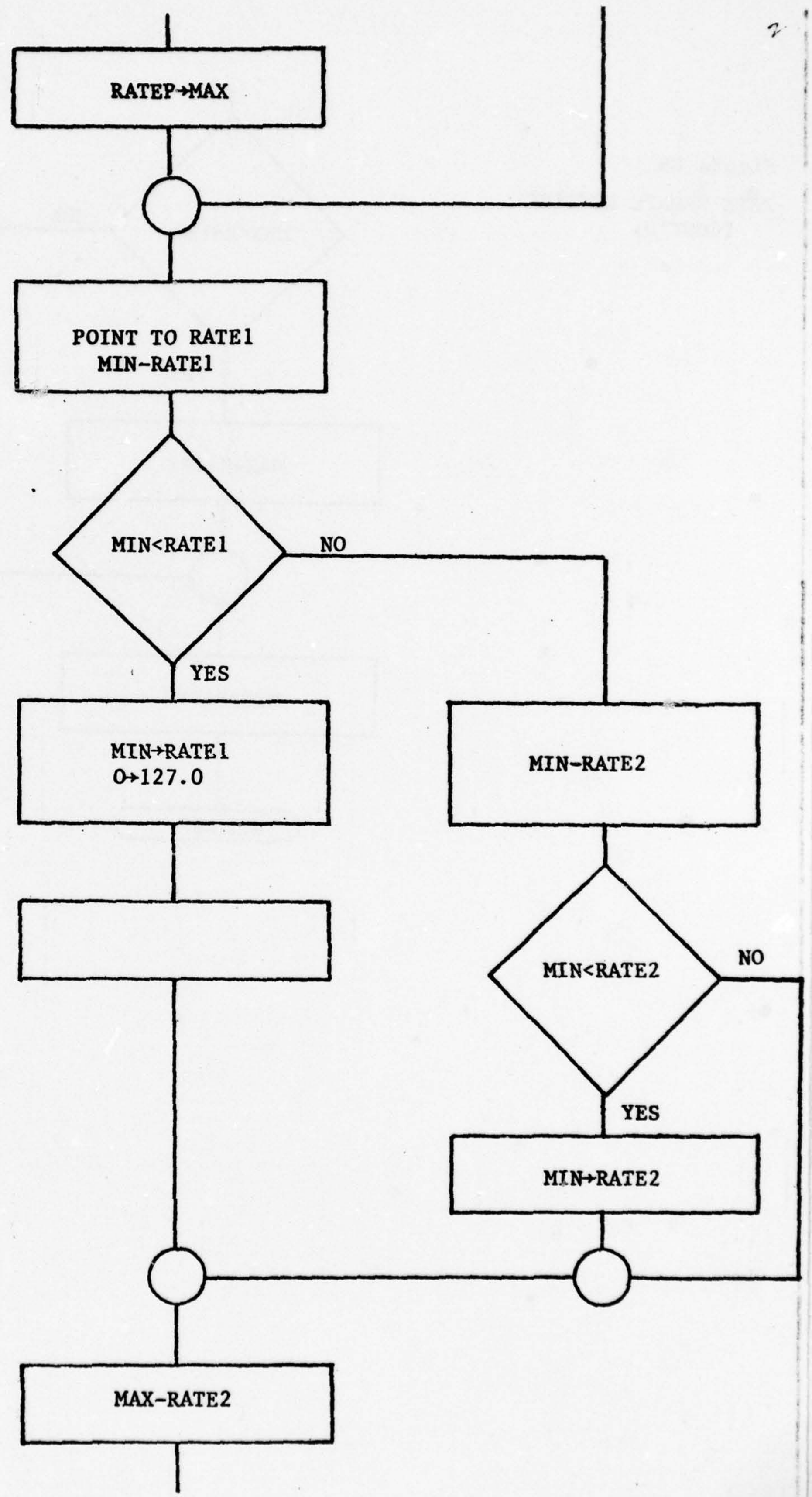


Figure C6

RATE UPDATE ROUTINE
(CONT'D)

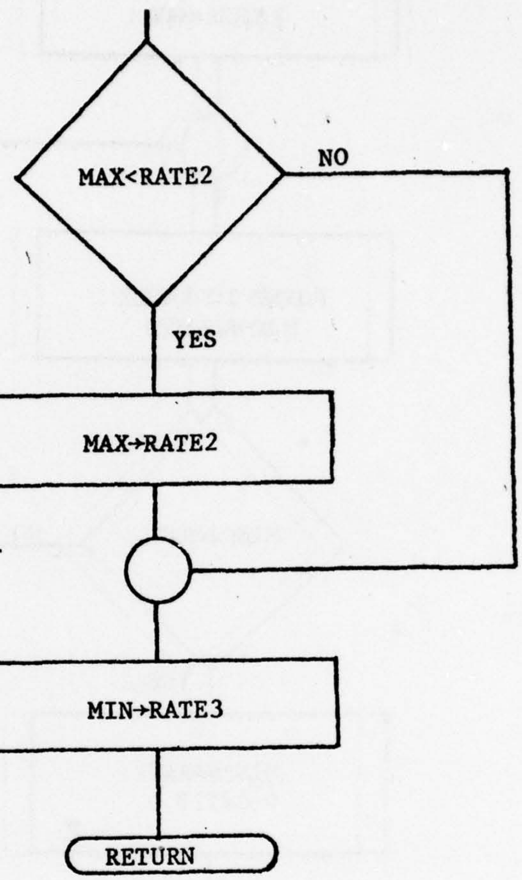


Figure C7

RATE CALCULATION SUBROUTINE

20 NOV 78

$F = 1500/E$

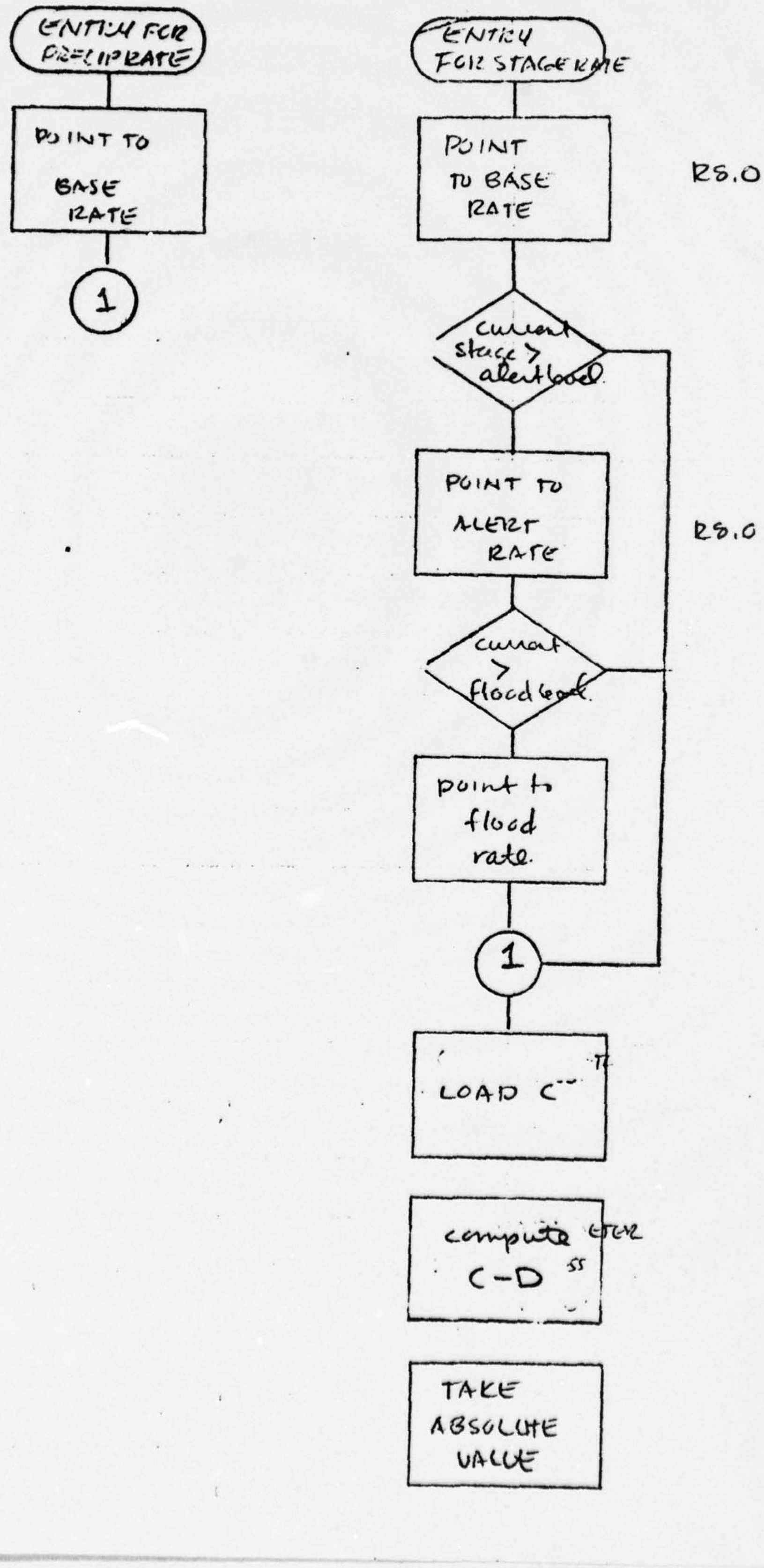
$E = A + B/|C-D|$

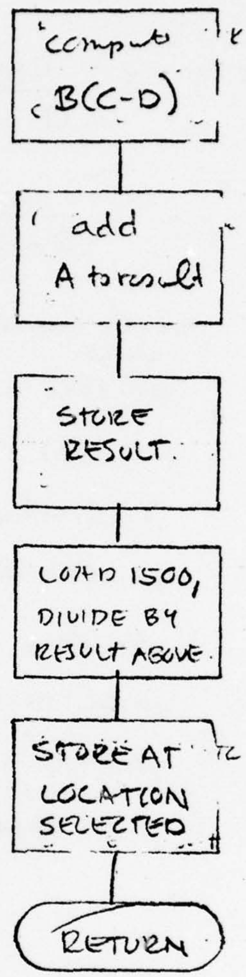
F is in 4min loops/TRANS.

A is in trans/HR x100.

1500 is loops/hr x100.

CALL SEQUENCE	TO CALCULATE STAGE RATE EXECUTE
SEP CALL	SEP CALL
,A (CALCSR)	,A(CALCSR)
,A.0(C)	,A.0(STAGE1)
,A.0 (D)	,A.0(STAGE3)
,A.0 (B)	,A.0(CON1)
,A.0 (STORAGE POINTER)	,A.0(RATES)


ENTRY FOR PRECIP RATE
POINT TO BASE RATE
1
ENTRY FOR STAGE RATE
POINT TO BASE RATE
R8.0
current stage > alert level
POINT TO ALERT RATE
R8.0
current > flood level
point to flood rate
1
LOAD C
compute C-D
TAKE ABSOLUTE VALUE


compute B(C-D)
add A to result
STORE RESULT.
LOAD 1500, DIVIDE BY RESULT ABOVE.
STORE AT LOCATION SELECTED
RETURN

GENERAL CALCULATION SUBROUTINE

$$G = A*(D-E)/(B-C)+F \quad = \quad \frac{RANGE*(FMEAS-FMIN)}{(FMAX-FMIN)} + MIN$$

utilizes math ROM

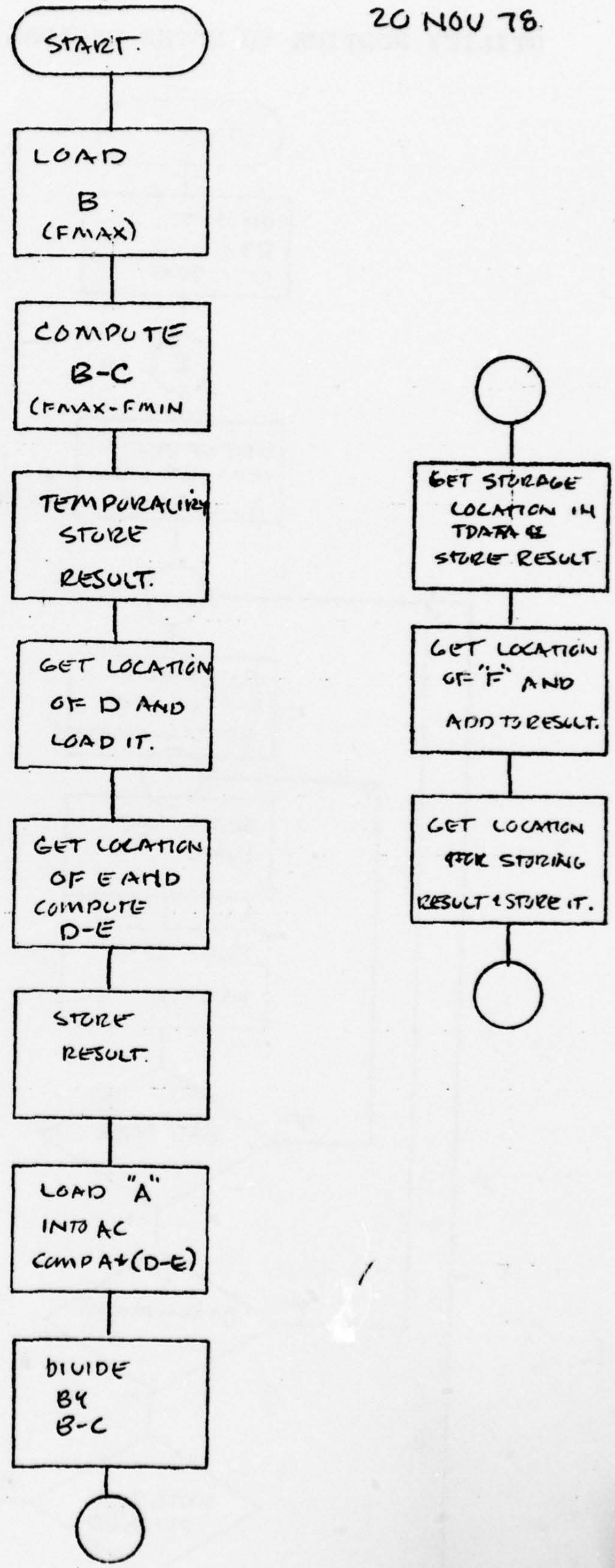
$$= \quad \frac{RANGE}{(FMAX-FMIN)} (FMIN - FMEAS) + CURRENT\ VALUE$$

call sequence	to calc current stage.	to calc min stage
SEP CALL	SEP CALL	SEP CALL
,A (CALC)	,A (CALC)	,A (CALC)
,A.0 (D)	,A.0 (FSTAGE)	,A.0 (FMIN)
,A.0 (E)	,A.0 (FMIN)	,A.0 (FSTAGE)
,A	,4000_{10}	,4000_{10}
,A.0 (TDATA)	,A.0 (TDATA)	,A.0 (:)
,A.0 (F)	,A.0 (SMIN)	,A.0 (STAGE)
,A.0 (DESTINATION)	,A.0 (STAGE)	,A.0 (SMIN)

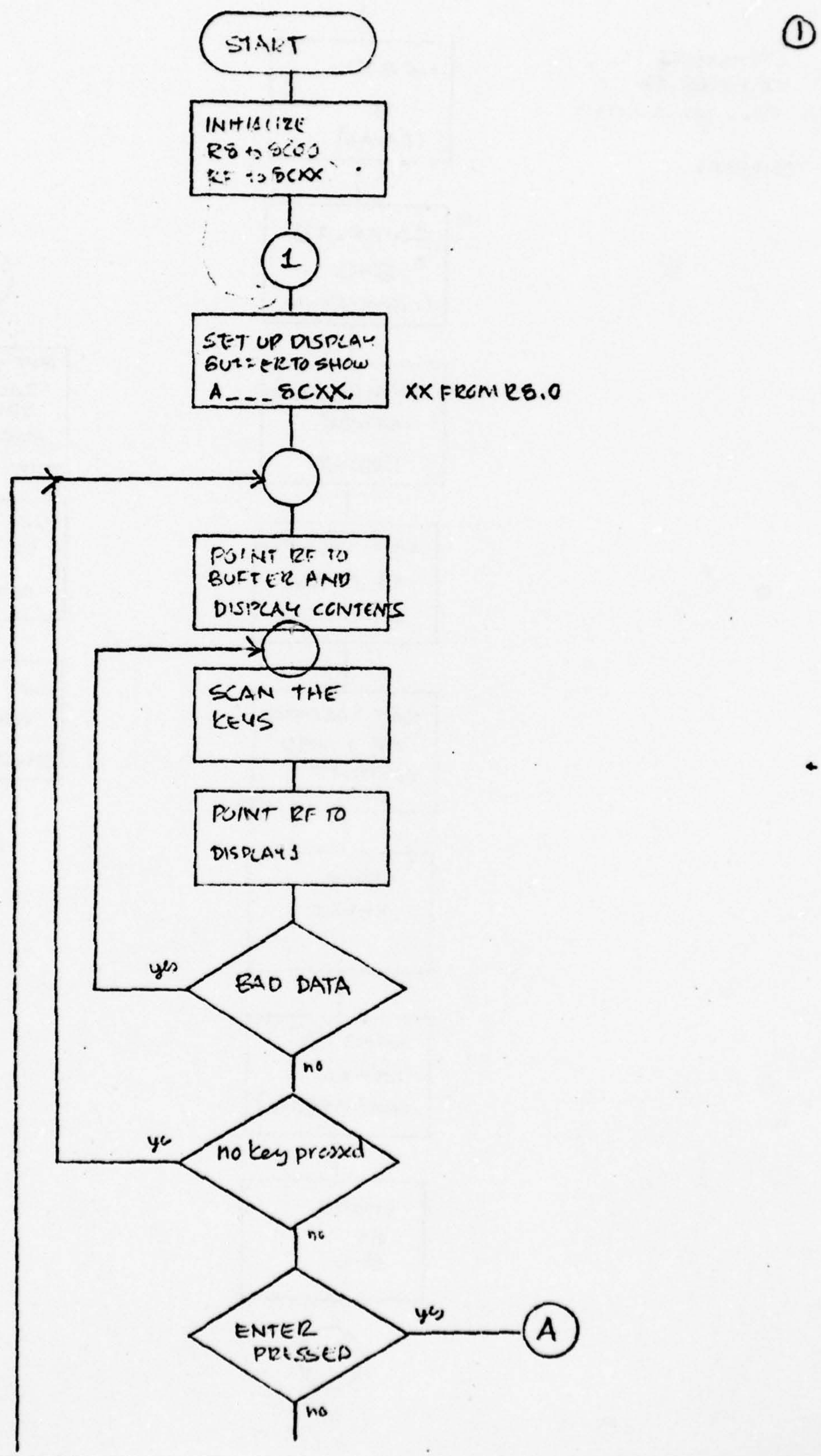
20 NOV 78.

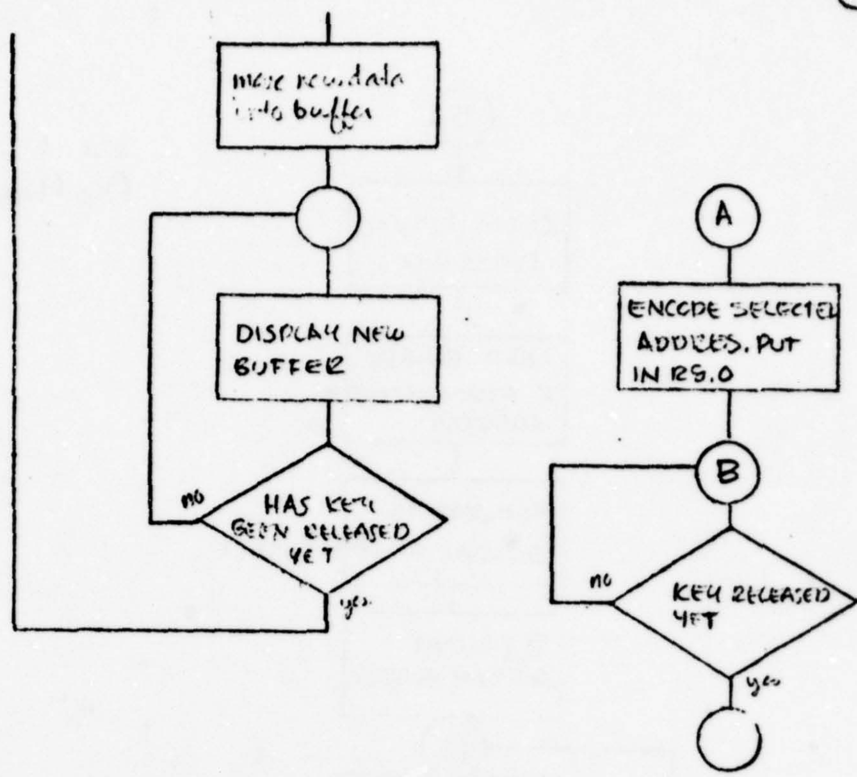
UTILIZES REGISTERS
SCRT R3, R4, R5, R6
R6 to Pass parameters

MATH REGISTERS.

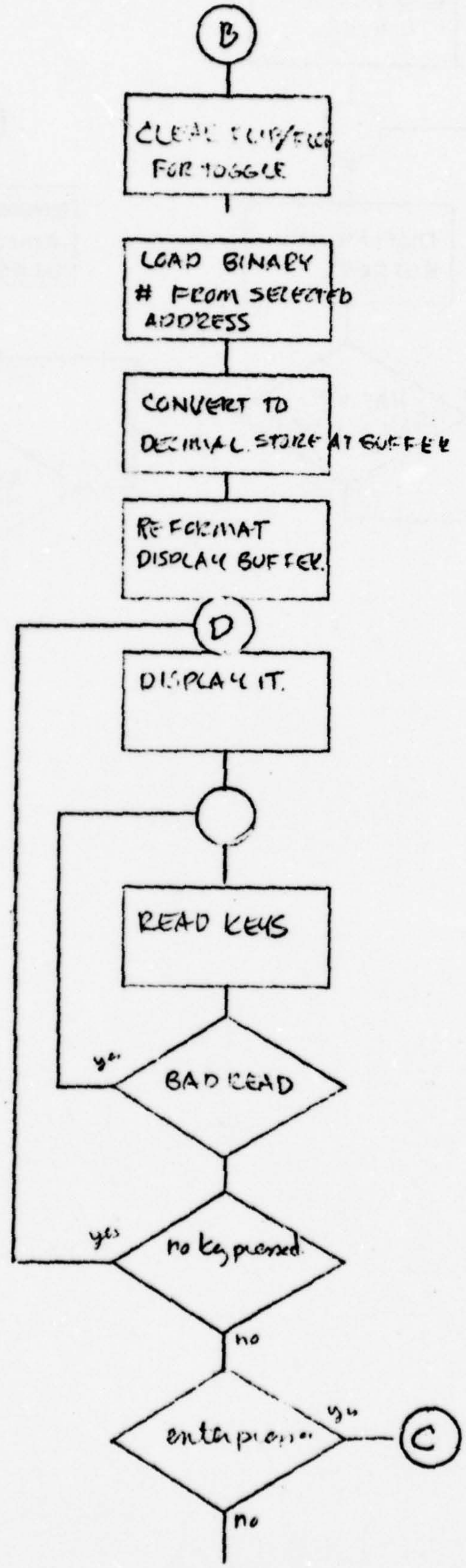


UTILITY ROUTINE TO ENTER DECIMAL NUMBERS/READ MEMORY

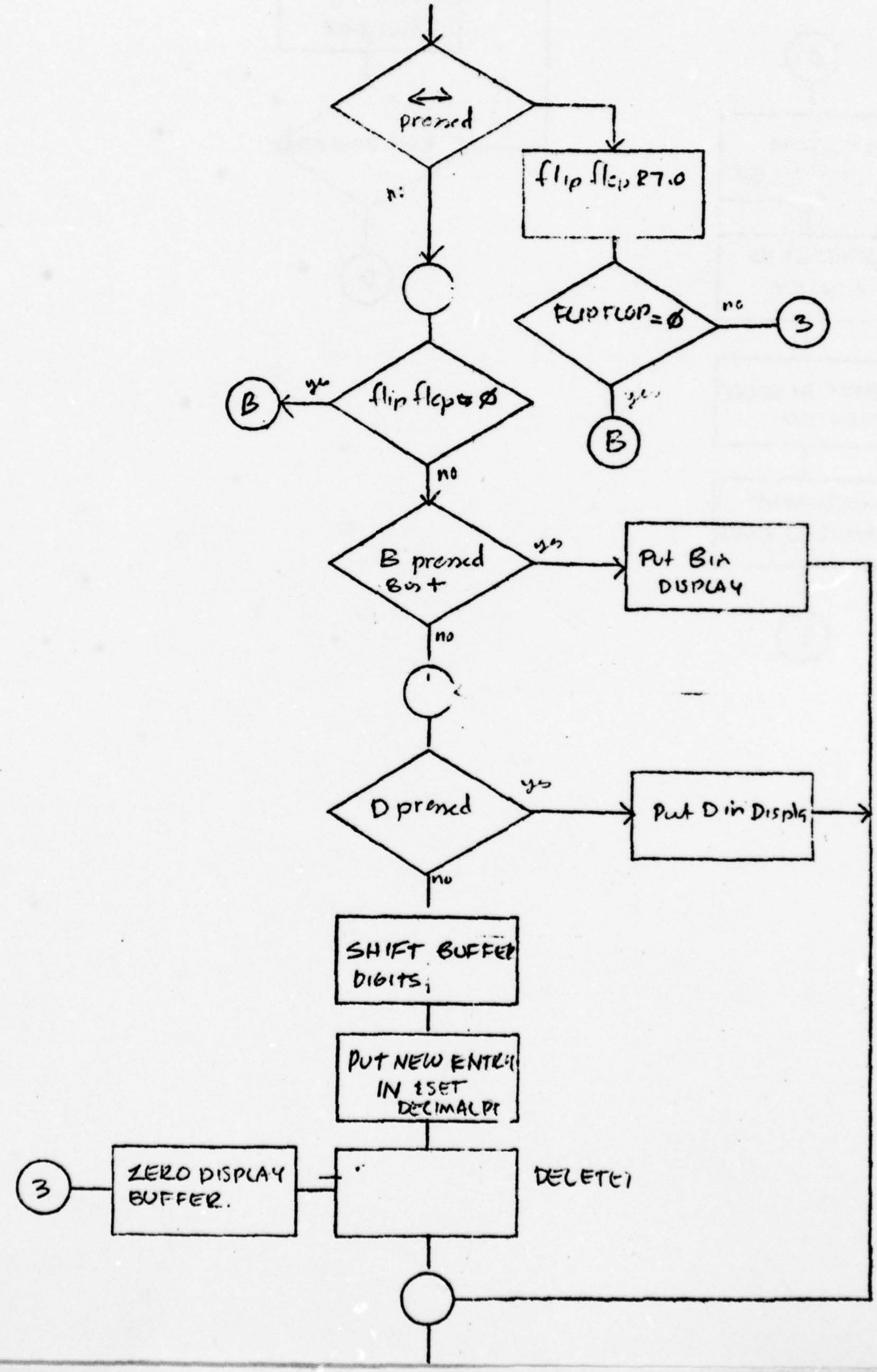



move newdata into buffer
DISPLAY NEW BUFFER
HAS KEY BEEN RELEASED YET
no
yes
A
ENCODE SELECTED ADDRESS. PUT IN RS.0
B
KEY RELEASED YET
no
yes

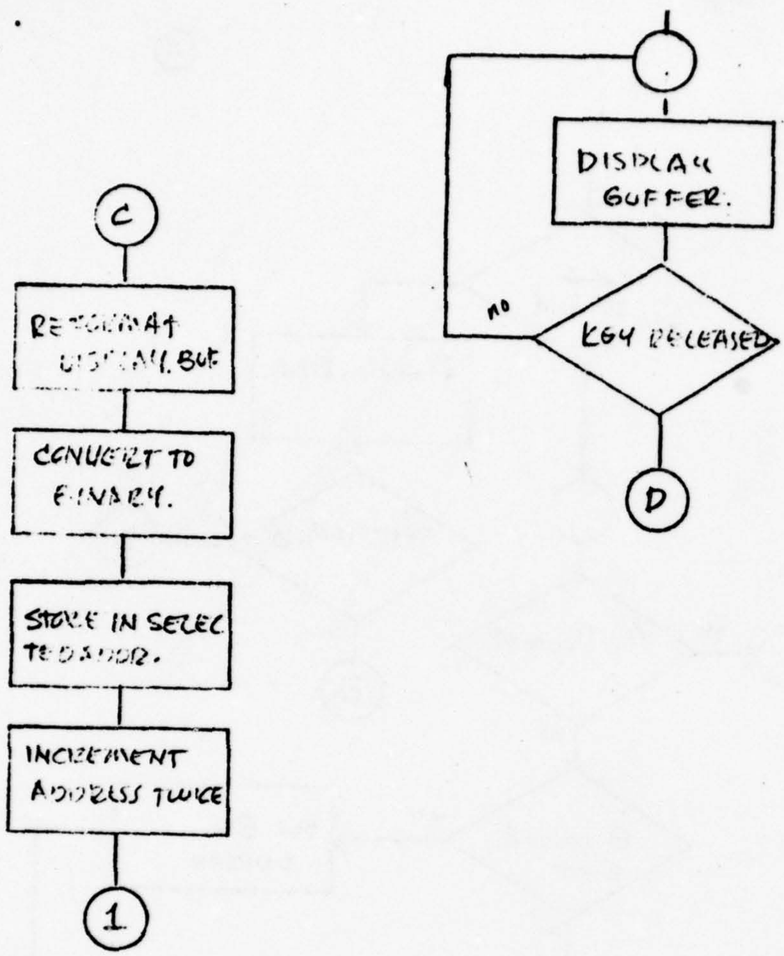
Use R7.0 as the toggle flip flop.



④



↔ pressed
no
flip flop 87.0
FLIPFLOP=Ø
no
3
yes
B
yes
B
flip flop ≠ Ø
no
B pressed 8 or +
yes
Put B in DISPLAY
no
D pressed
yes
Put D in Displa
no
SHIFT BUFFER DIGITS;
PUT NEW ENTRY IN &SET DECIMAL PT
3
ZERO DISPLAY BUFFER.
DELETED


C
REFORMAT DISPLAY BUF
CONVERT TO BINARY.
STORE IN SELECTED ADDR.
INCREMENT ADDRESS TWICE
1
DISPLAY BUFFER.
NO
KEY RELEASED
D

RR/DCP CHECK-OUT SHEET

Date:____________________ Operator:____________________________

Location:____

HEX ENTRIES - PROCEDURE 1

ADDRESS	CONTENTS	SETUP	DESCRIPTION
8C62			31 Bit ID Code
8C63			"
8C64			"
8C65			"
8C52			00 FDC Precip 01 Bucket

DECIMAL ENTRIES - PROCEDURE 2

ADDRESS	CONTENTS	SETUP	DESCRIPTION
8C36			R_1, Base Transmission Rate x 100 (Trans/Hr x 100)
8C38			R_2, Alert Transmission Rate x 100 (Trans/Hr x 100)
8C3A			R_3, Flood Transmission Rate x 100 (Trans/Hr x 100)
8C3C			A, Slore factor stage stream (0-100)
8C3E			B, Slore factor - Precip. (0-100)
8C40			Alert Level x 100 (feet x 100)
8C42			Flood Level x 100 (feet x 100)
8C2C			Current Stage x 100 (feet x 100)
8C32			Current Precip Level x 100 (inches x 100)

TESTING/CALIBRATING PROGRAMS

168$P	8C28________	Minimum Stage Level
170$P	8C2A________	Minimum Precip Level if "1" appears bucket is selected
178$P	8C2C________	Current Stage
	8C32________	Current Precip
180$P		Transmits Values at 8C66
158$P	8C46________	RF FWD
	8C48________	RF REF

PROCEDURE 1 - DISPLAYING/ENTERING HEX NUMBERS

PRESS KEY	DISPLAY ADDRESS	DISPLAY BYTE	COMMENTS
R	---	---	Resets processor
RU	0.0.0.0.	C0	Runs utility program at location 8000. Dots in address field indicate a new address can be entered. Address entries shift in display from right to left. The contents of that address immediately displayed. To look at the next and subsequent locations, press "inc".
8	0.0.0.8.	XX	
C	0.0.8.C.	XX	
6	0.8.C.6.	XX	
2	8.C.6.2.	XX	
	8C62	XX.	To alter a byte in memory, press ↔ until the field select dots are in the byte field. Pressing ↔ again will shift the select to the address field.
CE	8C62	CE.	With byte field selected key entries go to byte field. Merely retype the byte if a mistake is made. This applies to the address selection also.
inc	8C63	XX.	inc moves the byte displayed (before inc pressed) into the selected memory. The next address is selected and displayed.

X indicates that the contents are indeterminate.

PROCEDURE 2 - DISPLAYING/ENTERING DECIMAL NUMBERS

PRESS KEY	DISPLAY	COMMENTS
R	-------	resets processor
RU	0.0.0.0. CO	runs utility program
160	0.1.6.0. F8.	selects address 160
$P 36	A 8C2.0. A 8C3.6.	runs program at address 160. The A means the address mode is selected. Only the last two digits of the address can be altered. Press keys until desired address is displayed.
inc	b 0 0100	Displays the contents of that address.
	"b" is positive sign "d" is negative sign	The keyboard is locked so that the contents cannot be changed until "inc" is pressed. Pressing "inc" moves displayed data back to memory and returns to the address select mode.
	b 0. 0.0.0.0.	Pressing ↔ once allows new data to be input. Key entries are considered decimal entries. Typing a d or b will change the sign to d or b. Entries shift in the display from right to left.
inc	A 8C3.8.	Pressing ↔ again will restore the original contents of memory to display and lock the keyboard as before. The value last displayed is moved to memory and the program returns to the address select mode until the next address displayed.

RR/DCP OPERATOR INSTRUCTIONS

CALIBRATING STAGE (PARAMETER 1)

(1) Enter current stage into address 8C2C using Procedure 2.

(2) Press R, RU, 168, $P. This will run a program which measures the stage, and computes the minimum value achievable assuming the current stage is correct.

(3) After measing and calculating (5 sec), the program will jump to the decimal display program. The address of SMIN (Stage Minimum) will be displayed. Press "inc" to see the contents. Note the sign "b" is +, "d" is negative.

(4) If this value is lower than the instruments desired minimum slip the belt off and rotate the wheel. Each turn is equivalent to 1 foot.

(5) Run the calibration program and adjust the wheel until the proper minimum is computed.

CALIBRATING PRECIPITATION (PARAMETER 2)

(1) Precip does not need to be calibrated if the bucket method is used to measure precip levels. Running the program with the bucket selected (01 in 8C52) will display a 1.

(2) Enter current precip level in 8C52.

(3) Press R, RU, 170, $P. This will run a program which measures the precip level, and computes the minimum value achievable assuming the current precip level is correct. After measuring and calculating (5 sec), the program will jump to the Decimal Display/Enter Program.

(4) The address of PMIN (Precip Minimum) will be displayed. Press "inc" to see the contents. Note the sign "b" is +, "d" is negative.

(5) If this value is lower than the instruments actual minimum, slip the belt off the gear and rotate the gear. Each turn is equivalent to .25 inches.

(5) Run the calibration program and adjust the gear until the proper minimum is computed.

ACQUIRE DATA

(1) To exercise the data acquisition program press R, RU, 178, $P.

(2) The program will measure the parameters, calculate the values and branch to the decimal display program. The contents of memory can then be examined.

TRANSMIT

(1) To exercise the transmitter press R, RU, 180, $P.

(2) The normal transmission will be made using the 10 located at 8C62. After the transmission RF act and RF reflected will be measured. The program will branch to the decimal display program so the resultant values can be examined.

MEASURING TRANSMIT POWER

(1) To measure transmit power, press R, RU, 158, $P.

(2) The microprocessor will measure RF-FWD and RF-REF, then branch to the decimal display program. The values at location 8C46 (RF-FWD) and 8C48 (RF-REF) should correspond to values set for that transmitter.

APPENDIX D

Table I. PARTS LIST FOR BOARD #1 CPU BOARD

BOARD 1

U1, U16	CD4040AE
U2	CDP1802CD
U3	CD4028 B
U4	CD4049 UB
U5	CD4050 B
U6	CD4001 B
U7	CDP1852CD
U8, U9	CD4011A
U10	CD4051B
U11	CD4016A
U12	AD537KD
U13	CD4098B
U14	CD40106B
U15	CD4068B
U17	CD4007

Table I. PARTS LIST FOR BOARD #1 CPU BOARD

MODEL 254-3869

R1 20K	CR1 IN757	C1 1uf.	TC XO Vectra 50.2223-A
R2 100K	Q1 2N2222.	C2,C3 5pf	X1 32.768K. MODEL 7710
R3 4.7K	Q2 2N2906	C4 .1ufd	
R4 10K	CR2 5.1v zener	C5 .001ufd	
R5 47Ω	CR3 IN4148	C6 .01ufd	
R6 1M	Q3 CA3160	C7 .1ufd.	
R7 22M.	Q4 2N2906	C8 .001ufd.	
R8 1.5m		C9 10ufd	
R9 150K		C10 .01	
R10 10K		C11 .015ufd.	
R11 1K.		C12 .01	
R12 4.7K		C13 1ufd	
R13 390K ?		C14 1ufd.	
R14 1M		C15-C20 .01ufd.	
R15 1M.		C21 33pf.	
R16 100K			
R17 100K			
R18 100K	R30 10K		
R19 470K.	R31 10K.		
R20 2.2M.	RF choke.		
R21,22,23,24 100K.	R32 1m		
R25 1K	R33 1K.		
R26 2.2K			
R27. 4.7K			
R28 909Ω.			
R29 1K.			

Table II. PARTS LIST FOR BOARD #2 - MEMORY

U1 - U3	IM6604 WG
U4	CDP1832
U5	CDPR582
U6, U7	CDP1822
U8	CDP1852CD
U9	CD4555B
C10	CD4049UB
C11	CD4023B
C12	CD4013A.

R1	47 Ω
R2	100 Ω
R3	10K
R4	470 Ω
R5	4.7 K.
R6	470K
R7	1.0M
R8	100K.
R9	470K
R10	47K.
R11	1.0M
R12	10K,
R13	24K.

CR1	IN4148
CR2	IN4148
CR3	TS5600
CR4	TS5600
CR5	IN4148
CR6	IN5344
CR7	IN5344.
CR8	MR500.
SCR1	2N4441

Q1	2N2906.
Q2	2N2222
Q3	2N2222.
Q5	2N5190
Q4	CA~~3080~~ 3018
C1	10 ufd
C2	10 ufd.
C3	.01 ufd
C4	.001
C5-C12	.01

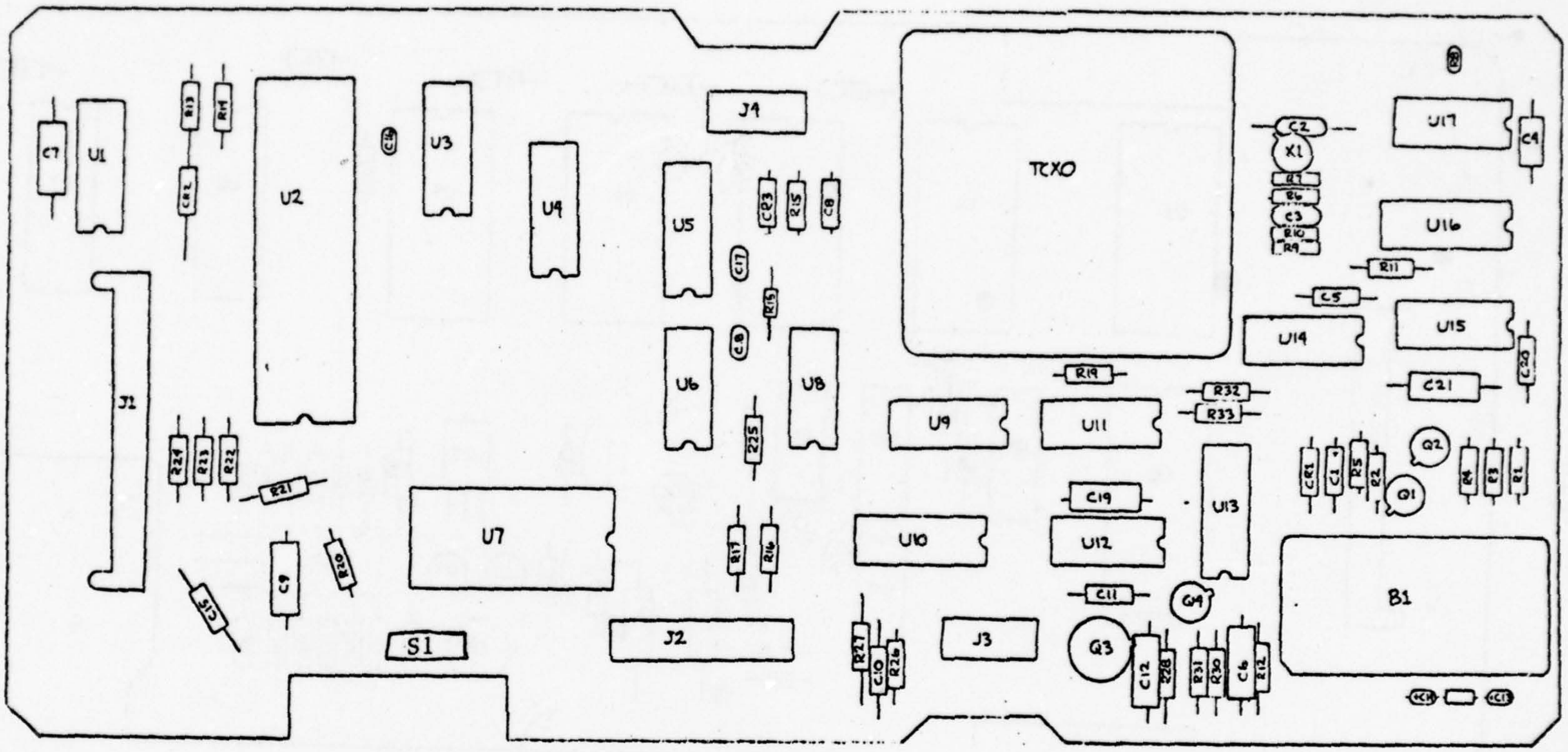


Figure D.1. CPU LAYOUT BOARD #1

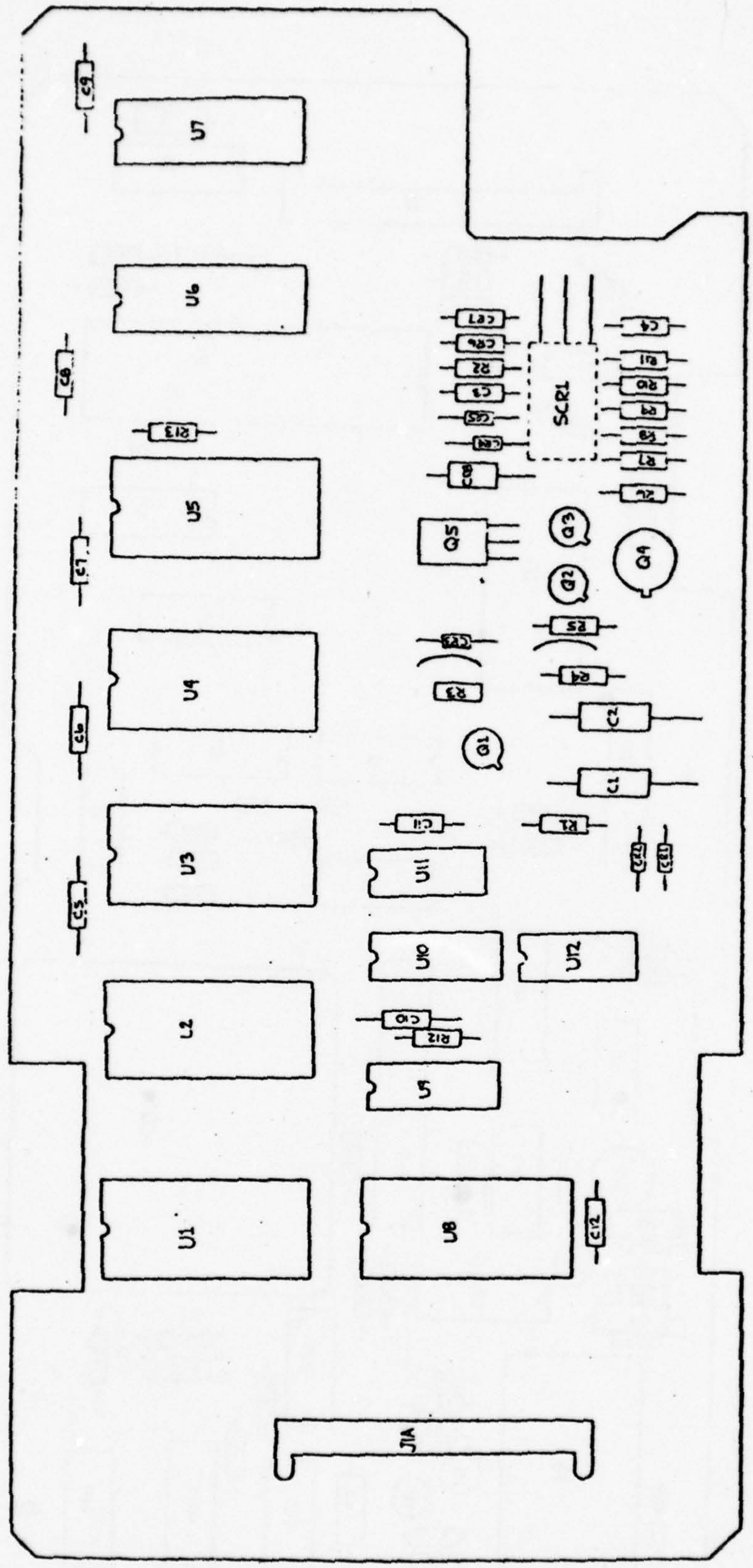


Figure D.2. MEMORY LAYOUT BOARD #2

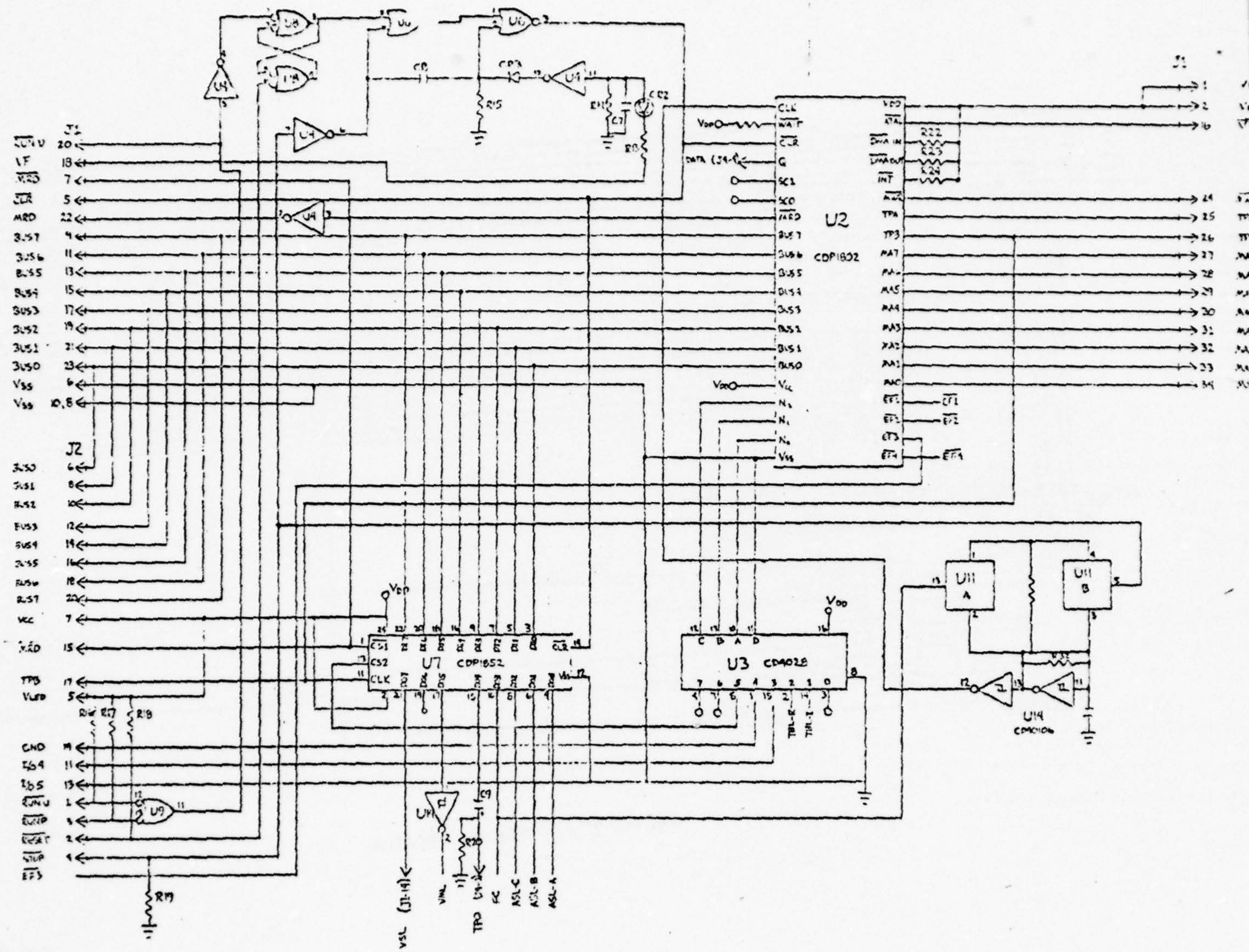


Figure D.3. CPU, STARTUP CONTROL, CLOCK

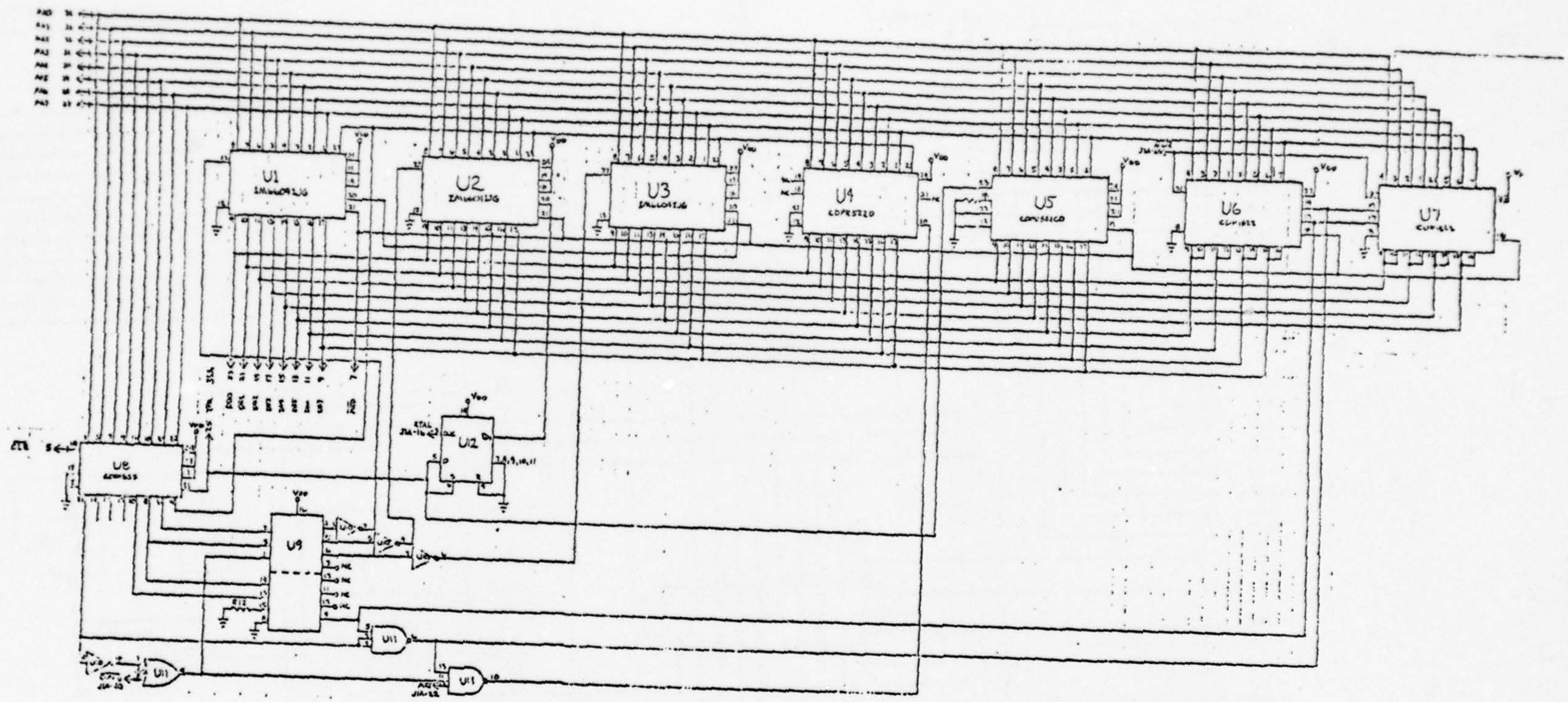


Figure D.4. MEMORY SECTION

DCP1-2

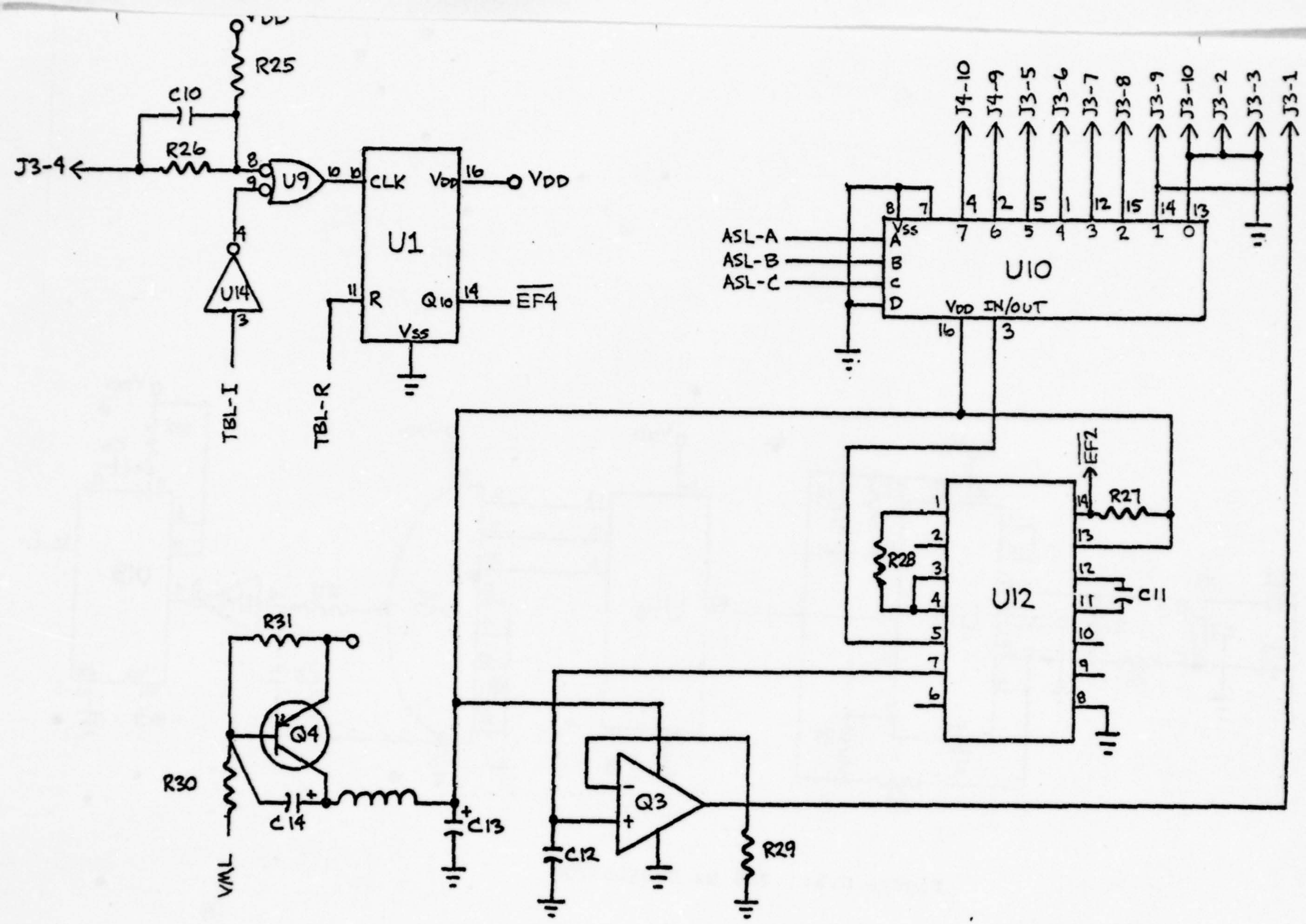


Figure D.5 INSTRUMENTATION INTERFACE

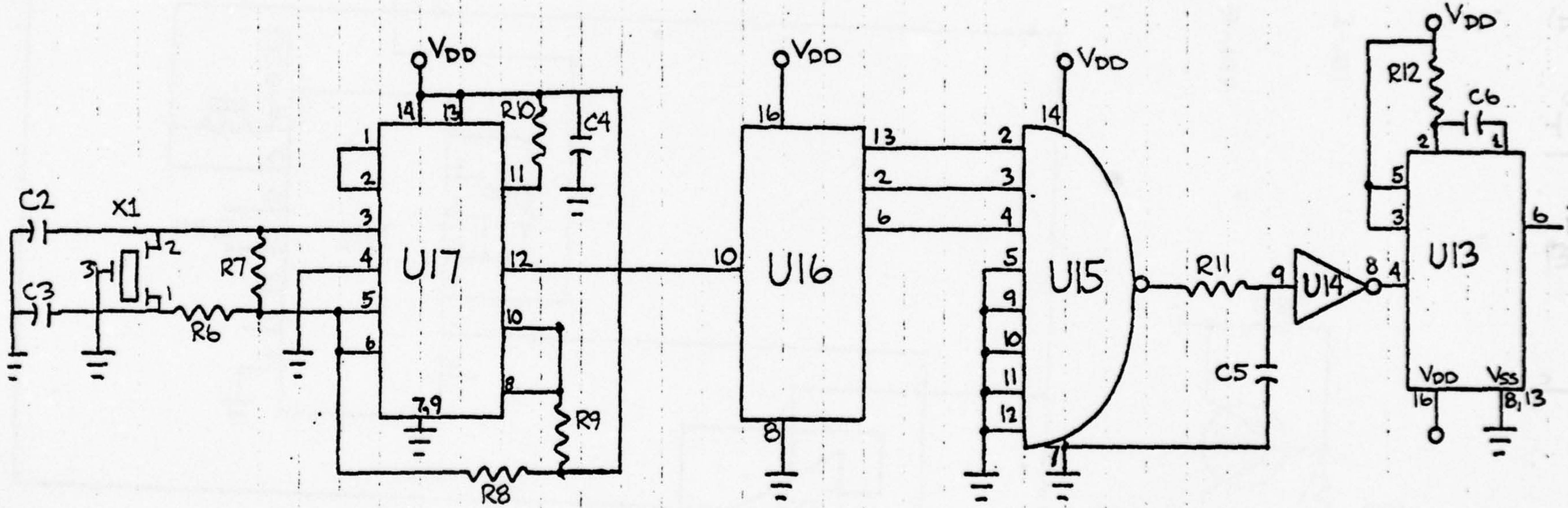


Figure D.6. 200 Hz OSCILLATOR

DCP1-4 12/78

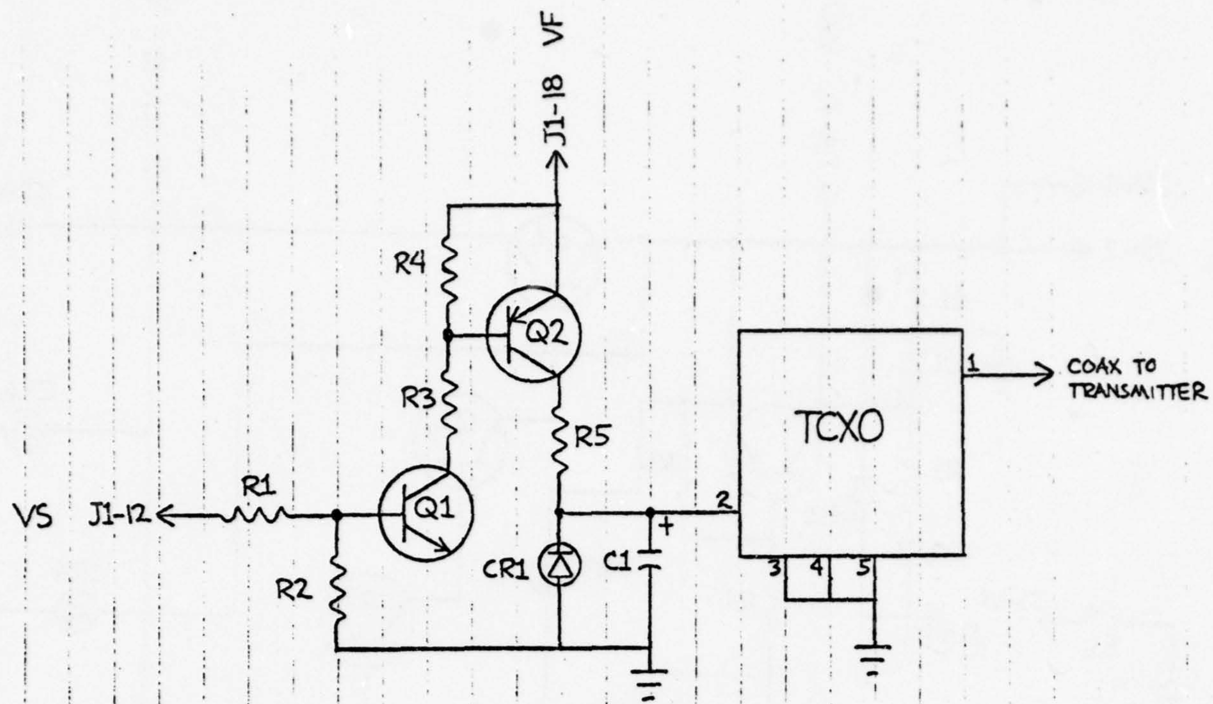


Figure D.7. TCXO POWER

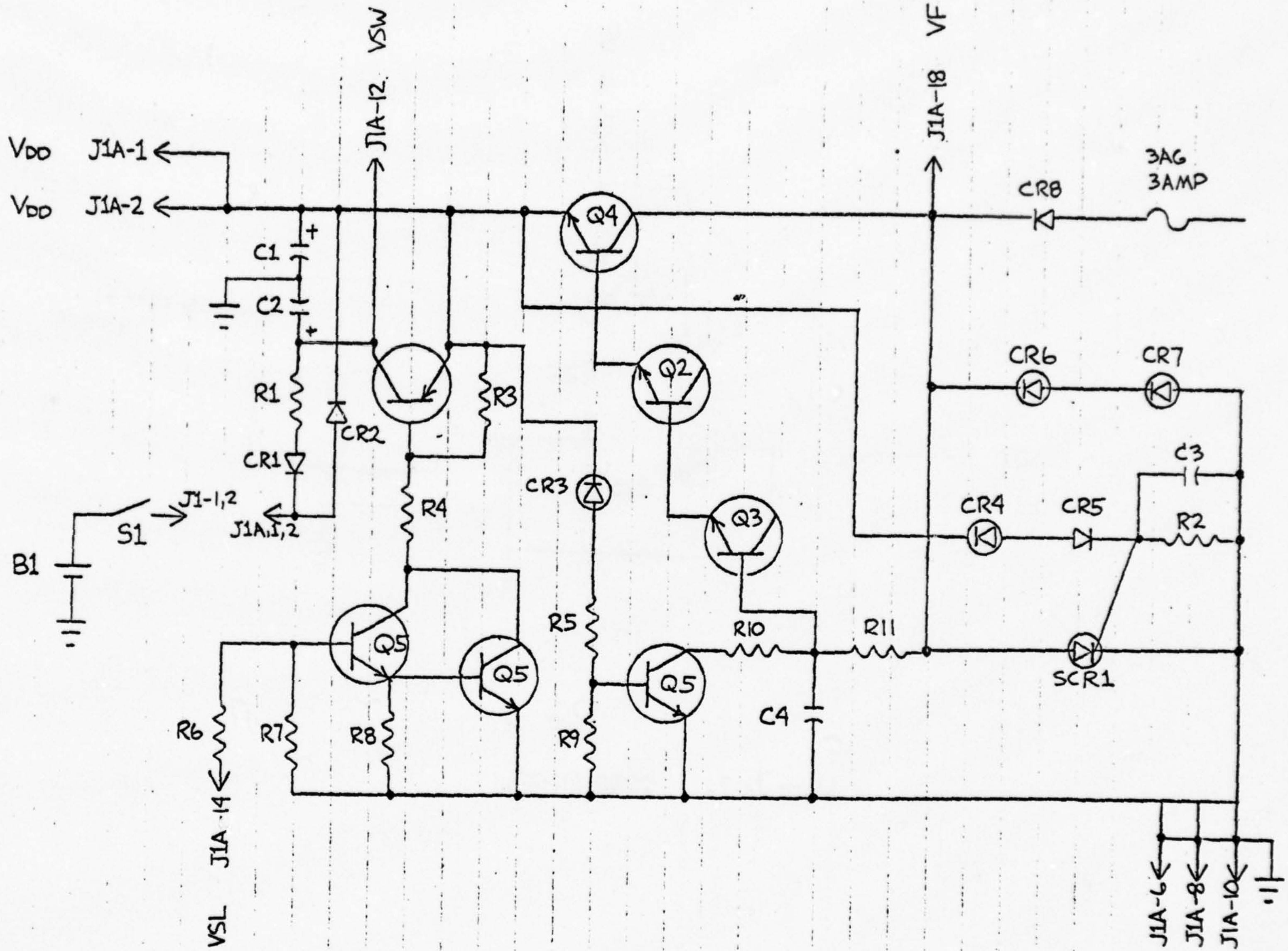


Figure D.8. POWER SUPPLY

DCP1-6

```
FL LOC  COSMAC CODE     SOURCE LINE

                        ..DCP EXECUTIVE PROOGRAM
                        ..
                        ..
                        ..REGISTER ASSIGNMENTS
        #0003           PC=R3
        #0004           CALL=R4
        #0005           RETN=R5
                        ..SUBROUTINE ADDRESSES
        #03F2           CALC=#03F2
        #0393           CALCSR=#0393
        #03B1           CALCPR=#03B1
        #0302           ENCODE=#0302
        #0200           GXMIT=#0200
        #0431           LDELY1=#0431
        #0435           LDELY2=#0435
        #0461           MEASR= #0461     0465
        #02EC           RND=    #02EC
        #034D           UPDATE=#034D
        #C249           LOADOP=#C249
        #C257           STOROP=#C257
        #C25B           STORE=#C25B
        #C24D           LOAD =#C24D
        #C00D           SDCON=#C00D
                        ..RAM LOCATIONS
        #8C3C           CON1  =#8C3C
        #8C3E           CON2  =#8C3E
        #8C50           FLAG1 =#8C50
        #8C51           FLAG2=#8C51
        #8C52           FLAG3=#8C52
        #8C53           FLAG4=#8C53
        #8C54           FLAG5=#8C54
        #8C22           FMIN=#8C22
        #8C26           FPRECP=#8C26
        #8C24           FSTAGE=#8C24
        #8C5A           PAD=#8C5A
        #8C2A           PMIN=#8C2A
        #8C32           PRECP1=#8C32
        #8C34           PRECP2=#8C34
        #8C44           RAND=#8C44
        #8C4A           RATE1=#8C4A
        #8C4D           RATES=#8C4D
        #8C4E           RATEP=#8C4E
        #8C28           SMIN=#8C28
        #8C2C           STAGE1=#8C2C
```

```
     #8C2E          STAGE2=#8C2E
     #8C30          STAGE3=#8C30
     #8C66          TDATA=#8C66
                    ..
                    ..INITIALIZATION
                    ..
0000                ORG #00
0000 C08108         LBR #8108       ..BRANCH TO ENTRY OF MICRO
0005                ORG #05                                     TERM R0
0005 F88CB8         LDI #8C;PHI R8  ..8C INTO R8.1
0008 F800A7         LDI #00;PLO R7  ..00 INTO R7.0
000B F8 FF B7       LDI #FF; PHI R7 ..TRANSMIT AFTER 2 CYCLE
000E F850           LDI A.0(FLAG1)
0010 A8             PLO R8
0011 F801           LDI #01
0013 58             STR R8          ..1 INTO FLAG1
0014 18             INC R8
0015 F800           LDI #00
0017 58             STR R8          ..0 INTO FLAG 2
0018 F844           LDI A.0(RAND)
001A A8             PLO R8
001B F800           LDI #00         ..SET UP RAND TO 0005
001D 58             STR R8
001E 18             INC R8
001F F805           LDI #05
0021 58             STR R8
0022 F84A           LDI A.0(RATE1) ..SET UP RATE1,2,3 WITH FF
0024 A8             PLO R8
0025 F8FF58         LDI #FF; STR R8 ..FF INTO RATE1
0028 1858           INC R8;  STR R8 ..FF INTO RATE 2
002A 1858           INC R8;  STR R8 ..FF INTO RATE3
002C F868           LDI A.0(TDATA)+#02
002E A8             PLO R8          ..POINT R8 TO BUCKET ACCUM
002F F80058         LDI #00; STR R8 ..0 OUT THE BUCKET
0032 1858           INC R8;  STR R8
0034 3050           BR #50
                    ..
                    ..EXECUTIVE PROGRAM
0050                ORG #50
                    ..IS IT TIME TO COLLECT NEW DATA?
0050 F851        EXEC1: LDI A.0(FLAG2)  ..POINT TO FLIP-FLOP
0052 A8             PLO R8
0053 08             LDN R8          ..TEST FLAG
0054 3AD4           BNZ EXEC2       ..DON'T COLLECT DATA IF FLAG IS
0056 F801           LDI #01         ..SET FLIP FLOP TO 1        SET
```

```
0058 58          STR R8
                 ..MAKE ROOM FOR NEW DATA
0059 D4          SEP CALL
005A C249        ,A(LOADOP)  ..GET STAGE 2
005C 8C2E        ,A(STAGE2)
005E D4          SEP CALL
005F C25B        ,A(STORE)   ..STORE IN STAGE 3
0061 D4          SEP CALL
0062 C24D        ,A(LOAD)    ..GET PRECIP1
0064 D4          SEP CALL
0065 C25B        ,A(STORE)   ..STORE IN PRECIP 2
0067 D4          SEP CALL
0068 C249        ,A(LOADOP)  ..GET STAGE 1
006A 8C2C        ,A(STAGE1)
006C D4          SEP CALL
006D C25B        ,A(STORE)   ..STORE IN STAGE 2
                 ..COLLECT NEW DATA
006F D4          SEP CALL    ..MEASURE DATA
0070 0465        ,A(MEASR)
0072 E3          SEX PC
0073 65          OUT 5       ..TURN OFF FAST CLOCK AND HIGH
0074 00          ,#00        ..VOLTAGE
                 ..PERFORM CONVERSIONS
0075 D4          SEP CALL
0076 03F2        ,A(CALC)    ..CONVERT FSTAGE TO FEET
0078 24          ,A.O(FSTAGE)
0079 22          ,A.O(FMIN)
007A 0FA0        ,4000       ..40 FT FULL SCALE
007C 66          ,A.O(TDATA)'..STORE INTERMED RESULT
007D 28          ,A.O(SMIN)
007E 2C          ,A.O(STAGE1) ..FINAL STAGE VALUE
007F F852        LDI A.O(FLAG3) ..DO WE CONVERT PRECIP ALDO
0081 A808        PLO R8 ; LDN R8
0083 3A91        BNZ EA1     ..BYPASS CONVERSION IN FLAG3=1
0085 D4          SEP CALL
0086 03F2        ,A(CALC)    ..CONVERT PRECIP TO INCHES
0088 26          ,A.O(FPRECP)
0089 22          ,A.O(FMIN)
008A 03E8        ,1000       ..10 INCHES FULL SCALE
008C 68          ,A.O(TDATA)+#02
008D 2A          ,A.O(PMIN)
008E 32          ,A.O(PRECP1)
008F 30A5 9B     BR EA2
0091 D4     EA1: SEP CALL    ..USING BUCKET,NO CONVERSION
0092 C249        ,A(LOADOP)  ..NECESSARY
0094 8C68        ,A(TDATA)+#02
```

```
0096 D4           SEP CALL      ..COPY BUCKET INTO PRECP1
0097 C257         ,A(STOROP)
0099 8C32         ,A(PRECP1)
                  ..RETURN IMMEDIATELY??
009B F854     EA2 LDI A.0(FLAG5)   ..GET FLAG5
009D A8           PLO R8
009E 08           LDN R8
009F 32A5         BZ EA2        ..IF FLAG5=0, DON'T RETURN
00A1 F800         LDI #00
00A3 58           STR R8
00A4 D5           SEP RETN          ..RETURN TO CALL PROGRAM
00A5 F850     EA2: LDI A.0(FLAG1) ..IS THIS THE FIRST LOOP
00A7 A8           PLO R8
00A8 08           LDN R8          ..GET THE FLAG
00A9 32C1         BZ EB2          ..IF ZERO NOT FIRST LOOP
00AB F800         LDI #00         ..FIRST LOOP , CLEAR FLAG
00AD 58           STR R8
00AE D4           SEP CALL        ..GET STAGE 1
00AF C249         ,A(LOADOP)
00B1 8C2C         ,A(STAGE1)
00B3 D4           SEP CALL        ..PUT IN STAGE 2
00B4 C25B         ,A(STORE)
00B6 D4           SEP CALL        ..PUT IN STAGE 3
00B7 C25B         ,A(STORE)
00B9 D4           SEP CALL
00BA C249         ,A(LOADOP)
00BC 8C32         ,A(PRECP1)   ..GET PRECIP 1
00BE D4           SEP CALL
00BF C25B         ,A(STORE)    ..PUT IN PRECIP 2
                  ..RATE CALCULATIONS
                  ..CALCULATE STAGE RATE
00C1 D4       EB2: SEP CALL    ..CALCULATE A+B*(C-D)
00C2 0393         ,A(CALCSR)   ..A IS RBASE
00C4 2C           ,A.0(STAGE1)
00C5 30           ,A.0(STAGE3) ..D
00C6 3C           ,A.0(CON1)   ..B
00C7 4D           ,A.0(RATES)  ..RAM STORAGE FOR RESULT
                  ..CALCULATE PRECIP RATE
00C8 D4           SEP CALL
00C9 03B1         ,A(CALCPR)    ..A IS RBASE
00CB 32           ,A.0(PRECP1) ..C
00CC 34           ,A.0(PRECP2) ..D
00CD 3E           ,A.0(CON2)    ..B
00CE 4E           ,A.0(RATEP)   ..RAM STORAGE FOR RESULT
                  ..UPDATE THE RATES
00CF D4           SEP CALL
00D0 034D         ,A(UPDATE)
00D2 30DC         BR EXEC3
```

```
                     ..
                     ..NO DATA HAS BEEN COLLECTED
                     ..DELAY TO MAKE UP FOR IT
00D4 F800       EXEC2: LDI #00     ..SET FLIP FLOP TO ZERO
00D6 58              STR R8
00D7 D4              SEP CALL
00D8 0431            ,A(LDELY1)
00DA FFFF            ,#FFFF  ← 0100
                     ..
                     ..ALL PATHS MEET HERE
                     ..IS IT TIME TO TRANSMIT
00DC E8         EXEC3: SEX R8
00DD F84A            LDI A.0(RATE1) ..POINT TO CURRENT RATE
00DF A8              PLO R8
00E0 97              GHI R7        ..GET CYCLE COUNTER
00E1 FC01            ADI #01       ..ADD ONE TO IT
00E3 B7              PHI R7        ..STORE IT
00E4 F7              SM            ..R7.1-RATE1
00E5 CB0139          LBNF EXEC4    ..
00E8 F800            LDI #00       ..OH BOY, WE GET TO TRANSMIT
00EA B7              PHI R7
00EB 17              INC R7
00EC D4              SEP CALL
00ED 02EC            ,A(RND)       ..GENERATE RANDOM #
00EF 9F              GHI RF        ..CHOP IT DOWN TO 12 BITS
00F0 FA0F            ANI #0F
00F2 BF              PHI RF
00F3 D4              SEP CALL      ..DELAY FOR A WHILE
00F4 0435            ,A(LDELY2)
                     ..ALL DONE WITH DELAY...MEASURE DATA AGAIN
00F6 D4              SEP CALL
00F7 0461 0465       ,A(MEASR)     ..TURNS ON FAST CLOCK ALSO
                     ..CALCULATE AGAIN
00F9 D4              SEP CALL
00FA 03F2            ,A(CALC)
00FC 24              ,A.0(FSTAGE)
00FD 22              ,A.0(FMIN)
00FE 0FA0            ,4000
0100 66              ,A.0(TDATA)
0101 28              ,A.0(SMIN)
0102 5A              ,A.0(PAD)     ..THROW THIS AWAY
0103 F852            LDI A.0(FLAG3)
0105 A8              PLO R8
0106 08              LDN R8
0107 CA0114          LBNZ EC1      ..NO CALC NEC. IF FLAG3=1
010A D4              SEP CALL
```

```
                 --- ----
010B 03F2               ,A(CALC)
010D 26                 ,A.0(FPRECP)
010E 22                 ,A.0(FMIN)
010F 03E8               ,1000
0111 68                 ,A.0(TDATA)+#02
0112 2A                 ,A.0(PMIN)
0113 5A                 ,A.0(PAD)     ..THROW THIS AWAY
                        ..ENCODE DATA
0114 D4          EC1:   SEP CALL
0115 0302               ,A(ENCODE)
                        ..TRANSMIT DATA
0117 D4                 SEP CALL
0118 0200               ,A(GXMIT)
011A 20                 ,#20          ..32*8 CLOCK
011B 04                 ,#04          ..4 BYTES TO TRANSMIT
011C F853               LDI A.0(FLAG4)
011E A8                 PLO R8
011F 08                 LDN R8        ..GET FLAG 4
0120 3226               BZ EC3
0122 F800               LDI #00       ..IF SET, CLEAR IT AND RETURN
0124 58                 STR R8
0125 D5                 SEP RETN      ..RETURN TO CALL PROGRAM
                        ..NOW COMPENSATE FOR RANDOM DELAY
0126 D4          EC3:   SEP CALL
0127 C249               ,A(LOADOP)    ..GET OLD DELAY COUNTER
0129 8C44               ,A(RAND)
012B 9F                 GHI RF        ..CHOP DOWN TO 12 BITS
012C FA0F               ANI #0F
012E BF                 PHI RF
012F D4                 SEP CALL
0130 C00D               ,A(SDCON)     ..CALC.REMAINING DELAY
0132 0FFF               ,#0FFF
                        ..DELAY TO EVEN UP TIME
0134 D4                 SEP CALL
0135 0435               ,A(LDELY2)
0137 303E               BR EXEC5
                        ..DELAY WHEN NO TRANSMISSION HAS BEEN MADE
0139 D4          EXEC4: SEP CALL
013A 0431               ,A(LDELY1)
013C FFFF 1004          ,#FFFF
                        ..DELAY TO CREATE A 4 MINUTE CYCLE TIME
013E D4          EXEC5: SEP CALL
013F 0431               ,A(LDELY1)
0141 FFFF               ,#FFFF
0143 C00050             LBR EXEC1     ..GO TO BEGINNING
                        END
```

Symbol table

CALC	03F2	CALCPR	03B1	CALCSR	0393	CALL	0004
CON1	8C3C	CON2	8C3E	EA1	0091	EA2	00A5
EB2	00C1	EC1	0114	EC3	0126	ENCODE	0302
EXEC1	0050	EXEC2	00D4	EXEC3	00DC	EXEC4	0139
EXEC5	013E	FLAG1	8C50	FLAG2	8C51	FLAG3	8C52
FLAG4	8C53	FLAG5	8C54	FMIN	8C22	FPRECP	8C26
FSTAGE	8C24	GXMIT	0200	LDELY1	0431	LDELY2	0435
LOAD	C24D	LOADOP	C249	MEASR	0461	PAD	8C5A
PC	0003	PMIN	8C2A	PRECP1	8C32	PRECP2	8C34
RAND	8C44	RATE1	8C4A	RATEP	8C4E	RATES	8C4D
RETN	0005	RND	02EC	SDCON	C00D	SMIN	8C28
STAGE1	8C2C	STAGE2	8C2E	STAGE3	8C30	STORE	C25B
STOROP	C257	TDATA	8C66	UPDATE	034D		

```
LOC   COSMAC CODE LNNO   SOURCE LINE

                                ..TRANSMITTER ROUTINE
                                ..THIS ROUTINE CONTROLS THE TRANSMITTER
                                ..TO SEND MANCHESTER ENCODED DATA AT 100 HZ.
                                ..
0200                            ORG #200
                                ..TRANSMITTER CONSTANTS
                                ..BIT 3 (FAST CLOCK) AND
                                ..BIT 7 (HIGH VOLTAGE) SHOULD ALWAYS BE SET.
      #0094                     CPO=#[redacted]  ..POWER ON CONSTANT BIT 4
      #00B4                     CTO=#[redacted]  ..TRANSMITTER ON CON  BIT 5
      #00F4                     CCO=#[redacted]  ..CARRI[redacted] ON CONSTANT  BIT 6
      #0022                     SYNC1=#22   ..FIRST SYNC WORD (CONTAINS TWO
                                            ..CLOCK BITS ALSO
      #00EB                     SYNC2=#EB   ..SECOND SYNC WORD
                                ..CHARACTER CONSTANTS
      #0004                     EOT=#04
                                ..RAM LOCATIONS
      #0062                     ADDR=#62
      #006A                     TBUF=#6A
                                ..REGISTER ASSIGNMENTS
      #0003                     PC=R3
      #0004                     CALL=R4
      #0005                     RETURN=R5
                                ..
                                ..SEQUENCE TO TURN ON AND INITIALIZE TRANSMI
0200 E3                GXMIT:   SEX PC
0201 65                         OUT 5     ..TURN POWER ON
0202 ~~94~~ 88                  ,[redacted]88  TURN CLOCK ON
0203 D4                         SEP CALL      ..~~DELAY FOR WARM UP OF~~ 1 SEC
0204 02AF                       ,A(DELAY)        Delay 1/4 sec.
0206 [redacted] 192D            ,[redacted]
                                ..
0208 E3                [redacted]  SEX PC
0209 65   a            SEX PC   OUT 5     ..TURN TRANSMITTER ON
020A ~~D4~~ D8         OUT 5    ,~~CTO~~
020B E3 C4             #98      SEX PC
020C 65 C4             NOP      OUT 5     ..TURN CARRIER ON
020D F4 C4             NOP      ,CCO
020E [redacted] F68C   LDI 8C   ~~SEP CALL~~ LDI 8C  ..CARRIER LASTS FOR 4 SEC
020F [redacted] B8     PHI R8   ~~,A(DELAY)~~ PHI R8
0211 [redacted] C4 C4  NOP      ~~,#CB66~~
0213 D4                SEP CALL SEP CALL
0214 02AF              A(DELAY) ,A(DELAY)
0216 [redacted] 3243   ,#3243   ,#CB66
```

```
                    ..PREPARE TO TRANSMIT CLOCK
0218 7A             REQ      ..RESET Q---Q IS THE SERIAL OUTPUT L
0219 E6             SEX PC
021A 341A           B1 *     ..WAIT FOR EF1=0
021C 3C1C           BN1 *    ..WAIT FOR SIGNAL, EF1=1
021E       C4   NOP OUT 5    ..TURN OFF CARRIER
021F       C4   NOP ,ETO
                             ..BIT TO BE SENT
0220 D4             SEP CALL          ..DELAY TO AVOID OVERLAP
0221 02AF           ,A(DELAY)
0223 0001           ,#0001
0225 3C25           BN1 *    ..WAIT FOR SIGNAL
0227 7B             SEQ      ..TRANSMIT SECOND HALF OF FIRST BIT
                    ..TRANSMIT CLOCK BITS
0228 46    XCLOCK:  LDA R6 ..SET UP LOOP COUNTER
0229 AD             PLO RD
022A F808           LDI #08 ..INITIALIZE BIPHS BIT COUNTER TO 8
022C AC             PLO RC
022D F8AA  XC1:     LDI #AA ..SET UP CLOCK BYTE
022F AF             PLO RF
0230 D4             SEP CALL ..TRANSMIT BYTE
0231 0278           ,A(BIP)
0233 00             ,#00
0234 2D             DEC RD  ..DECREMENT COUNTER
0235 8D             GLO RD  ..TEST COUNTER
0236 3A2D           BNZ XC1 ..DONE WHEN COUNTER IS ZERO
                    ..DONE WITH CLOCK
                    ..
                    ..PREPARE TO TRANSMIT SYNC
0238 F822           LDI SYNC1         ..SET UP TRANSMIT BYTE
023A AF             PLO RF
023B D4             SEP CALL          ..TRANSMIT BYTE
023C 0278           ,A(BIP)
023E 00             ,#00
023F F8EB           LDI SYNC2         ..SET UP NEXT TRANSMIT BYTE
0241 AF             PLO RF
0242 D4             SEP CALL          ..TRANSMIT BYTE
0243 0278           ,A(BIP)
                    ..ALL DONE WITH SYNC TRANSMISSION
0245 00             ,#00
                    ..
                    ..PREPARE TO TRANSMIT ADDRESS
0246 F861           LDI A.0(ADDR)-#01
0248 A8             PLO R8
0249 F803           LDI #03 ..SET UP LOOP COUNTER
024B AD             PLO RD
```

```
024C 18      XA1:    INC R8
024D D4              SEP CALL        ..TRANSMIT WORD
024E 0276            ,A(BIPHS)
0250 01              ,#01     ..FROM LEFT TO RIGHT
0251 2D              DEC RD   ..DECREMENT COUNTER
0252 8D              GLO RD   ..TEST IT
0253 3A4C            BNZ XA1  ..GO FOR MORE?
0255 18              INC R8   ..POINT TO LAST 7 BITS
0256 F807            LDI #07
0258 AC              PLO RC
0259 D4              SEP CALL        ..TRANSMIT LAST 7 BITS
025A 0276            ,A(BIPHS)
025C 01              ,#01     ..FROM LEFT TO RIGHT
                     ..ALL DONE WITH ADDRESS
                     ..PREPARE TO TRANSMIT DATA
025D F869    XDATA:  LDI TBUF-1      ..SET UP POINTER TO ADDRESS :
025F A8              PLO R8
0260 46              LDA R6 ..SET UP LOOP COUNTER
0261 AD              PLO RD
0262 18      XD1:    INC R8       ..POINT TO BYTE
0263 D4              SEP CALL        ..TRANSMIT IT
0264 0276            ,A(BIPHS)
0266 00              ,#00
0267 2D              DEC RD   ..DECREMENT COUNTER
0268 8D              GLO RD   ..TEST COUNTER
0269 3A62            BNZ XD1  ..DONE WHEN COUNTER IS ZERO
                     ..DONE WITH DATA TRANSMISSION
                     ..
                     ..PREPARE TO TRANSMIT EOT CHARACTER
026B F804    XEOT:   LDI EOT ..SET UP TRANSMIT BYTE
026D AF              PLO RF
026E D4              SEP CALL        ..TRANSMIT IT
026F 0278            ,A(BIP)
0271 00              ,#00
                     ..ALL DONE
0272 E3              SEX PC   ..TURN OFF TRANSMITTER
0273 65              OUT 5
0274 00              ,#00
0275 D5              SEP RETURN      ..RETURN TO CALLING PROGRAM
                     ..BIPHS ROUTINE
                     ..THIS ROUTINE CONTROLS THE SERIAL I/O
                     ..OF DATA TO THE TRANSMITTER
0276 08      BIPHS:  LDN R8   ..ENTRY POINT TO LOAD BYTE
0277 AF              PLO RF   ..FROM MEMORY FOR TRANSMISSION
0278 E6      BIP:    SEX R6   ..POINT TO PARAMETER
0279 F800            LDI #00  ..LOAD A 0
027B F1              OR       ..OR IT WITH PARAMETER
```

```
027C 3282            BZ *+#06          ..IF ZERO BRANCH
027E 8F              GLO RF   ..NOT ZERO
027F FE              SHL      ..SHIFT BITS OUT TO LEFT
0280 3084            BR *+#04
0282 8F              GLO RF
0283 F6              SHR      ..SHIFT BITS OUT TO RIGHT
0284 AF              PLO RF   ..STORE MODIFIED BYTE
0285 3B94            BNF XB1  ..BRANCH IF BIT IS ZERO
0287 3C87            BN1 *    ..WAIT FOR SIGNAL
0289 7A              REQ      ..CLEAR Q
028A D4              SEP CALL ..DELAY TO AVIOD OVERLAP
028B 02AF            ,A(DELAY)
028D 0001            ,#0001
028F 3C8F            BN1 *    ..WAIT FOR SIGNAL
0291 7B              SEQ
0292 309F            BR XB2
0294 3C94   XB1:      BN1 *    ..WAIT FOR SIGNAL
0296 7B              SEQ      ..SET Q
0297 D4              SEP CALL          ..DELAY TO AVOID OVERLAP
0298 02AF            ,A(DELAY)
029A 0001            ,#0001
029C 3C9C            BN1 *
029E 7A              REQ      ..CLEAR Q
029F 2C     XB2:      DEC RC   ..DECREMENT BIT COUNTER
02A0 8C              GLO RC   ..TEST COUNTER
02A1 3AA8            BNZ XB3  ..BRANCH IN NOT ZERO
02A3 F808            LDI #08 ..RESET BIT COUNTER TO 8
02A5 AC              PLO RC
02A6 16              INC R6   ..INCREMENT BY PARAMETER
02A7 D5              SEP RETURN
02A8 D4     XB3:      SEP CALL
02A9 02AF            ,A(DELAY)
02AB 0001            ,#0001
02AD 3078            BR BIP   ..LOOP AGAIN
                     ..DELAY ROUTINE
                     ..THIS ROUTINE DELAYS
                     ..PROGRAM EXECUTION FOR
                     ..(PLACE EQUATION HEWE) SEC
                     ..
02AF 46     DELAY:   LDA R6-  ..GET HI BYTE OF DELAY
02B0 BE              PHI RE
02B1 46              LDA R6   ..GET LO BYTE OF DELAY
02B2 AE              PLO RE
02B3 2E     D1:      DEC RE   ..DECREMENT COUNTER
02B4 9E              GHI RE   ..TEST HI BYTE
02B5 3ABC            BNZ D2   ..BRANCH IF NOT ZERO
```

```
02B7 8E    00184          GLO RE    ..TEST LO BYTE
02B8 32C0  00185          BZ D3     ..ALL DONE IF ZERO
02BA 30B3  00186          BR D1     ..LOOP AGAIN
02BC 8E    00187   D2:    GLO RE    ..KILL SOME TIME
02BD 8E    00188          GLO RE    ..KILL SOME TIME
02BE 30B3  00189          BR D1     ..LOOP AGAIN
02C0 D5    00190   D3:    SEP RETURN

                00191               ..ALL DONE WITH DELAY ROUTINE
                00192               END
```

CA1802 Boston Systems Office Version 1B(15)
GXMIT.OBJ,GXMIT.LST=GXMIT.SRC

Symbol table

ADDR	0062	BIP	0278	BIPHS	0276	CALL	0004
CCO	00F4	CPO	0094	CTO	00B4	D1	02B3
D2	02BC	D3	02C0	DELAY	02AF	EOT	0004
GXMIT	0200	PC	0003	RETURN	0005	SYNC1	0022
SYNC2	00EB	TBUF	006A	XA1	024C	XB1	0294
XB2	029F	XB3	02A8	XC1	022D	XCLOCK	0228
XD1	0262	XDATA	025D	XEOT	026B		

```
FL LOC  COSMAC  LNNO   SOURCE LINE
        CODE
                       ..FDC SUBROUTINE
                       ..FREQUENCY TO DIGITAL CONVERSION
                       ..MAXIMUM SAMPLING GREQUENCY 5
                       ..REGISTER ASSIGNMENTS
        #000F          CNT=#0F      ..COUNT OF 0-1 TRANSITIONS
        #000D          REF=#0D      ..#SAMPLES IN ONE SECOND
        #000E          MEM=#0E      ..MEMORY OF PREVIOUS SAMPLE
        #0005          RETN=#05     ..RETURN ROUTINE
        #0008          PRAM=#08
   02C1                ORG #2C1     ..PROGRAM STARTS HERE
                       ..SELECT DEVICE
   02C1 E6        FDC: SEX R6       ..TAKE DEVICE # FROM
   02C2 65             OUT 5        ..PARAMETER LIST
                       ..INITIALIZE REGISTERS
   02C3 46             LDA R6       ..POINT PRAM TO
   02C4 A8             PLO PRAM     ..DATA STORAGE AREA
   02C5 F800           LDI #00      ..ZERO COUNTER
   02C7 AF             PLO CNT
   02C8 BF             PHI CNT
   02C9 AE             PLO MEM      ..ZERO SAMPLE MEMORY
   02CA F84C           LDI #4C      ..SET #4C8F INTO LOOP
   02CC BD             PHI REF      ..COUNTER.  THERE ARE 4B8F
   02CD F88F           LDI #8F      ..LOOPS IN ONE SECOND AT
   02CF AD             PLO REF      ..2 MHZ CLOCK.
                       ..THIS LOOP SAMPLES EF2 AT 19343 HZ
                       ..FOR CLOCK OF 2.476 MHZ
   02D0 3DE0     LOOP: BN2 F1       ..IF SAMPLE IS ZERO, BRANCH
   02D2 8E             GLO MEM      ..GET PREVIOUS SAMPLE
   02D3 3ADD           BNZ F2       ..BRANCH IF NO 0-1 TRANSITION
   02D5 1F             INC CNT      ..TRANSITION, INCREMENT COUNTER
   02D6 1E        F3:  INC MEM      ..SET A 1 IN SMAPLE MEMORY
   02D7 2D        F4:  DEC REF      ..ONE LESS CYCLE TO GO
   02D8 9D             GHI REF      ..TEST REFERENCE, HIGH BYTE
   02D9 3AD0           BNZ LOOP     ..COLLECT ANOTHER SAMPLE
   02DB 30E6           BR F6        ..REF = 0 ALL DONE
   02DD 8E        F2:  GLO MEM    ..A NOP STATEMENT
   02DE 30D7           BR F4
   02E0 F800      F1:  LDI #00      ..SAMPLE IS ZERO
   02E2 AE             PLO MEM      ..ZERO SAMPLE MEMORY
   02E3 AE             PLO MEM
   02E4 30D7           BR F4
   02E6 9F        F6:  GHI CNT      ..STORE FREQUENCY IN RAM
   02E7 58             STR PRAM     ..LOW BYTE FIRST
   02E8 18             INC PRAM      ..POINT TO NEXT LOCATION
   02E9 8F             GLO CNT      ..GET HIGH BYTE
   02EA 58             STR PRAM
   02EB D5             SEP RETN      ..RETURN TO CALLING PROGRAM
                       END
```

```
FL LOC  COSMAC CODE   SOURCE LINE

                             ..RANDOM NUMBER GENERATOR
                             ..LEAVES A RANDOM NUMBER IN R(F)
         #0004               CALL=R4
         #0005               RETN=R5
         #C249               LOADOP=#C249
         #8C44               RAND=#8C44
         #C04F               MPYOP=#C04F
         #C257               STOROP=#C257
   02EC                      ORG #2EC
   02EC D4                   SEP CALL
   02ED C249                 ,A(LOADOP)
   02EF 8C44                 ,A(RAND)
   02F1 D4                   SEP CALL      ..MULTIPLY BY #0C35
   02F2 C04F                 ,A(MPYOP)
   02F4 0300                 ,A(MULT)
   02F6 9F                   GHI RF        ..CHOP OFF MSB
   02F7 FA7F                 ANI #7F
   02F9 BF                   PHI RF        ..STOPE IT
   02FA D4                   SEP CALL      ..STORE NEW RANDOM NUMBER
   02FB C257                 ,A(STOROP)
   02FD 8C44                 ,A(RAND)
   02FF D5                   SEP RETN      ..RETURN TO CALL PROGRAM
   0300 0C35           MULT: ,#0C35        ..MULTIPLIER
                             END
```

```
FL LOC  COSMAC CODE        LNNO   SOURCE LINE

                           00001          ..DEFINITIONS
        #0004              00002          CALL=R4
        #0005              00003          RETURN=R5
        #006A              00004          TBUF=#6A ✓
        #0066              00005          TDATA=#66✓
   0302                    00006          ORG #302
   0302 98                 00007  ENCODE: GHI R8
   0303 B9                 00008          PHI R9
   0304 F86A               00009          LDI A.0(TBUF)
   0306 A9                 00010          PLO R9
   0307 F86A               00011         LDI A.0(TDATA)+4
   0309 A8                 00012          PLO R8
   030A F802               00013          LDI #2
   030C AD                 00014          PLO RD
   030D 28                 00015  E1:     DEC R8
   030E 08                 00016          LDN R8
   030F FA3F               00017          ANI #3F
   0311 BF                 00018          PHI RF
   0312 D4                 00019          SEP CALL
   0313 032A               00020          ,A(PARITY)
   0315 08                 00021          LDN R8
   0316 7E                 00022          SHLC
   0317 7E                 00023          SHLC
   0318 7E                 00024          SHLC
   0319 FA03               00025          ANI #3
   031B 52                 00026          STR R2
   031C 28                 00027          DEC R8
   031D 08                 00028          LDN R8
   031E FE                 00029          SHL
   031F FE                 00030          SHL
   0320 F1                 00031          OR
   0321 BF                 00032          PHI RF
   0322 D4                 00033          SEP CALL
   0323 032A               00034          ,A(PARITY)
   0325 2D                 00035          DEC RD
   0326 8D                 00036          GLO RD
   0327 3A0D               00037          BNZ E1
   0329 D5                 00038          SEP RETURN
                           00039          ..NOW COMES THE PARITY ROUTINE
   032A F800               00040  PARITY: LDI #0
   032C AF                 00041          PLO RF
   032D F806               00042          LDI #6
   032F AC                 00043          PLO RC
   0330 9F                 00044          GHI RF
```

```
0331 59              STR R9
0332 9F        P1:   GHI RF
0333 F6              SHR
0334 3B37            BNF P2
0336 1F              INC RF
0337 BF        P2:   PHI RF
0338 2C              DEC RC
0339 8C              GLO RC
033A 3A32            BNZ P1
033C 8F              GLO RF
033D F6              SHR
033E 3345            BDF P3
0340 09              LDN R9
0341 F940            ORI #40
0343 3048            BR P4
0345 09        P3:   LDN R9
0346 F9C0            ORI #C0
0348 59        P4:   STR R9
0349 19              INC R9
034A D5              SEP RETURN
                     END
```

```
FL LOC   COSMAC CODE         SOURCE LINE

                                  ..UPDATE RATE SUBROUTINE
         #000F                    AC=RF
         #8C4D                    RATES=#8C4D
         #8C4B                    RATE2=#8C4B
         #8C4A                    RATE1=#8C4A
         #0005                    RETN=R5
   034D                           ORG #34D
   034D E8                   UPDATE: SEX R8
   034E 87                        GLO R7
   034F FF04                      SMI #04              R7.0-4
   0351 3B60                      BNF U1               branch if R7.0<4
   0353 F84B                      LDI A.0(RATE2)
   0355 A8                        PLO R8
   0356 72                        LDXA
   0357 AF                        PLO AC
   0358 F0                        LDX
   0359 28                        DEC R8
   035A 73                        STXD
   035B 8F                        GLO AC
   035C 73                        STXD
   035D F800                      LDI #00
   035F A7                        PLO R7
   0360 F84D                 U1:  LDI A.0(RATES)
   0362 A8                        PLO R8
   0363 72                        LDXA
   0364 BF                        PHI AC
   0365 F7                        SM
   0366 336C                      BDF U2
   0368 F0                        LDX
   0369 AF                        PLO AC
   036A 3070                      BR U3
   036C 9F                   U2:  GHI AC
   036D AF                        PLO AC
   036E F0                        LDX
   036F BF                        PHI AC
   0370 F84A                 U3:  LDI A.0(RATE1)
   0372 A8                        PLO R8
   0373 9F                        GHI AC
   0374 F7                        SM
   0375 337F                      BDF U5
   0377 9F                        GHI AC
   0378 58                        STR R8
   0379 F800                      LDI #00
   037B A7                        PLO R7
```

```
037C 18
037D 3086
037F 9F
0380 18
0381 F7
0382 3386
0384 9F
0385 58
0386 8F
0387 F7
0388 338C
038A 8F
038B 58
038C 18
038D 9F
038E 58
038F E2
0390 D5
```

```
        INC R8
        BR U6
U5:     GHI RF
        INC R8
        SM
        BDF U6
        GHI RF
        STR R8
U6:     GLO RF
        SM
        BDF U7
        GLO RF
        STR R8
U7:     INC R8
        GHI RF
        STR R8
        SEX R2
        SEP RETN
        END
```

```
L LOC  COSMAC LNNO   SOURCE LINE
       CODE
              00001      ..RATE CALCULATION ROUTINE
              00002       ..ENTRY POINTS AT CALCSR OR CALCPR
              00003       ..REGISTER ASSIGNMENTS
       #0004  00004       CALL=R4
       #0005  00005       RETN=R5
       #000D  00006       MA=RD
              00007       ..SUBROUTINE ADDRESSES
       #C249  00008       LOADOP=#C249
       #C262  00009       COMPOP=#C262
       #C24D  00010       LOAD=#C24D
       #C031  00011       SMEM=#C031
       #C053  00012       MPY=#C053
       #C1D5  00013       ADD1=#C1D5
       #C257  00014       STOROP=#C257
       #C252  00015       LODCON=#C252
       #C0A1  00016       DIVOP=#C0A1
              00017       ..VARIABLE ADDREESES
       #8C2C  00018       STAGE1=#8C2C
       #8C40  00019       ALERT=#8C40
       #8C38  00020       SRALRT=#8C38
       #8C42  00021       FLOOD=#8C42
       #8C3A  00022       SRFLD=#8C3A
       #8C36  00023       RBASE=#8C36
       #8C5A  00024       PAD=#8C5A
              00025       ..
              00026       ..ENTRY TO CALCULATE THE STAGE RATE
  0393        00027       ORG #393
  0393 F836   00028   CALCSR: LDI A.0(RBASE)
  0395 A8     00029       PLO R8
  0396 D4     00030       SEP CALL
  0397 C249   00031       ,A(LOADOP)      ..LOAD STAGE
  0399 8C2C   00032       ,A(STAGE1)
  039B D4     00033       SEP CALL
  039C C262   00034       ,A(COMPOP)      ..IS IT GRAATER THAN ALERT LEVEL
  039E 8C40   00035       ,A(ALERT)
  03A0 3BB4   00036       BNF CA1         ..BRANCH IF NO
  03A2 F838   00037       LDI A.0(SRALRT)
  03A4 A8     00038       PLO R8
  03A5 D4     00039       SEP CALL
  03A6 C262   00040       ,A(COMPOP)      ..IS IT > FLOOD LEVEL
  03A8 8C42   00041       ,A(FLOOD)
  03AA 3BB4   00042       BNF CA1         ..BRANCH IF NO
  03AC F83A   00043       LDI A.0(SRFLD)
  03AE A8     00044       PLO R8          ..POINT R8 TO FLOOD RATF
```

```
03AF 30B4        BR CA1            ..SKIP OVER OTHER ENTRY POINT
                 ..
                 ..ENTRY TO CALCULATE THE PRECIP RATE
03B1 F836   CALCPR: LDI A.0(RBASE)
03B3 A8          PLO R8            ..POINT R8 TO BASE RATE
03B4 98     CA1: GHI R8
03B5 ~~20~~BD       ~~GHI MA~~ PHI MA
03B6 46          LDA R6            ..POINT MA TO C
03B7 AD          PLO MA
03B8 D4          SEP CALL          ..LOAD C
03B9 C24D        ,A(LOAD)
03BB 46          LDA R6            ..POINT MA TO D
03BC AD          PLO MA
03BD D4          SEP CALL          ..SUBTRACT D FROM C
03BE C031        ,A(SMEM)
03C0 D4          SEP CALL
03C1 03E1        ,A(ABS)           ..TAKE ABSOLUTE VALUE
03C3 46          LDA R6            ..POINT MA TO B
03C4 AD          PLO MA
03C5 D4          SEP CALL          ..MULT B*(C-D)
03C6 C053        ,A(MPY)
03C8 88          GLO R8            ..POINT MA TO A
03C9 AD          PLO MA
03CA D4          SEP CALL
03CB C1D5        ,A(ADD1)          ..ADD A
03CD D4          SEP CALL
03CE C257        ,A(STOROP)        ..STORE IN PAD
03D0 8C5A        ,A(PAD)
03D2 D4          SEP CALL
03D3 C252        ,A(LODCON)        ..LOAD 1500
03D5 05DC        ,1500             ..A DECIMAL MUMVVER
03D7 D4          SEP CALL
03D8 C0A1        ,A(DIVOP)         ..DIVIDE
03DA 8C5A        ,A(PAD)
03DC 46          LDA R6            ..POINT TO STORAGE
03DD AD          PLO MA
03DE 8F          GLO RF            ..STORE LOW BYTE ONLY
03DF 5D          STR RD
03E0 D5          SEP RETN          ..RETURN TO CALL PROGRAM
                   ..ABSOLUTE VALUE PROGRAM
                 ..REGISTER ASSIGNMENTS
                 ..
03E1 9F     ABS: GHI RF
03E2 FE          SHL
03E3 3BEE        BNF DONE
03E5 9F          GHI RF
03E6 FBFF        XRI #FF
03E8 BF          PHI RF
03E9 8F          GLO RF
03EA FBFF        XRI #FF
03EC AF          PLO RF
03ED 1F          INC RF
03EE D5     DONE: SEP R5
                 END
```

```
FL LOC  COSMAC CODE      SOURCE LINE

                              ..GENERAL CALCULATION ROUTINE
                              ..COMPUTES G=A/(B-C)*(D-E)+F
                              ..REGISTER ASSIGNMENTS
        #0004                 CALL=R4
        #0005                 RETN=R5
        #000D                 MA=RD
        #000F                 AC=RF
                              ..SUBROUTINE ADDRESSES
        #C249                 LOADOP=#C249
        #C02D                 SMOP=#C02D
        #C257                 STOROP=#C257
        #C24D                 LOAD=#C24D
        #C031                 SMEM=#C031
        #C04F                 MPYOP=#C04F
        #C0B7                 DIV=#C0B7
        #C1D5                 ADD1=#C1D5
        #C25B                 STORE=#C25B
                              ..VARIABLE ADDRESSES
        #8C20                 FMAX=#8C20
        #8C22                 FMIN=#8C22
        #8C5A                 PAD=#8C5A
                              ..
   03F2                      ORG #03F2
   03F2 D4               CALC: SEP CALL
   03F3 C249                  ,A(LOADOP)        ..LOAD B
   03F5 8C20                  ,A(FMAX)
   03F7 D4                    SEP CALL
   03F8 C02D                  ,A(SMOP)          ..COMPUTE B-C
   03FA 8C22                  ,A(FMIN)
   03FC D4                    SEP CALL
   03FD C257                  ,A(STOROP)        ..STORE RESULT
   03FF 8C5C                  ,A(PAD)+#02
   0401 46                    LDA R6            ..POINT RD TO D
   0402 AD                    PLO MA
   0403 D4                    SEP CALL
   0404 C24D                  ,A(LOAD)          ..LOAD D
   0406 46                    LDA R6            ..POINT RD TO E
   0407 AD                    PLO MA
   0408 D4                      SEP CALL
   0409 C031                  ,A(SMEM)          ..COMPUTE D-E
   040B D4                    SEP CALL
   040C C257                  ,A(STOROP)        ..STORE RESULT
   040E 8C5A                  ,A(PAD)
```

```
0410 46          LDA R6
0411 BF          PHI AC          ..LOAD A INTO AC
0412 46          LDA R6
0413 AF          PLO AC
0414 D4          SEP CALL
0415 C04F        ,A(MPYOP)       ..COMPUTE A*(D-E)
0417 8C5A        ,A(PAD)
0419 F85C        LDI A.0(PAD)+#02
041B AD          PLO MA
041C D4          SEP CALL
041D C0B7        ,A(DIV)         ..DIVIDE BY (B-C)
041F 46          LDA R6
0420 AD          PLO MA
0421 D4          SEP CALL        ..STORE INTERMEDIATE
0422 C25B        ,A(STORE)
0424 46          LDA R6          ..POINT MA TO F
0425 AD          PLO MA
0426 D4          SEP CALL
0427 C1D5        ,A(ADD1)        ..ADD F
0429 46          LDA R6          ..POINT MA TO STORAGE AREA
042A AD          PLO MA
042B D4          SEP CALL
042C C25B        ,A(STORE)       ..STORE RESULT
042E D5          SEP RETN        ..RETURN TO CALL PROGRAM
                 END

L LOC  COSMAC LNNO  SOURCE LINE
       CODE
                    ..LONG DELAY ROUTINE
                    ..REGISTER ASSIGNMENTS
       #0004        CALL=R4
       #0005        RETN=R5
                    ..SUBROUTINE ASSINMENTS
       #02AF        DELAY=#02AF
                    ..
0431                ORG=#0431
0431 46       LDELY1: LDA R6     ..GET PARAMETERS FROM CALL
0432 BF               PHI RF
0433 46               LDA R6
0434 AF               PLO RF
0435 D4       LDELY2: SEP CALL   ..CALL OTHER DELAY PROGRAM
0436 02AF             ,A(DELAY)                      ROUTINE
0438 0007             ,#0007
043A 2F               DEC RF     ..DECREMENT LOOP COUNTER
043B 9F               GHI RF     ..TEST IT
043C 3A42             BNZ LD1    ..BRANCH FOR MORE?
043E 8F               GLO RF
043F 3A35             BNZ LDELY2 ..BRANCH FOR MORE?
0441 D5               SEP RETN   ..ALL DONE..RF=0
0442 9F       LD1:    GHI RF     ..WASTE SOME TIME
0443 3A35             BNZ LDELY2 ..LOOP AGAIN
                      END
```

```
                                    .. Tipping Bucket
                                    .. with limiter incase it fails as a sdupurang.
145                                 ORG 445
445     D4          BUCKET:         SEP CALL
446,7   C249                        ,A(LOADOP)
448,9   8C68                        ,A(TDATA)+#02
44A     D4                          SEP CALL
44B,C   C1EB                        ,A(ADDCON)
44D,E   0100                        ,256
44F,0   F8FF                        LDI#FF
451     AD                          PLO RD
452     E8                          SEX R8          Reg
                                                    .. Any address will do.
453,4   3F5D        BUCK2:          BN4 BUCK1       0->255    255-0
455     61                          OUT1            1->256    255-0

456     2F                          DEC AC
457     8D                          GLO RD
458,9   325D                        BZ BUCK1
45A     2D                          DEC RD
45B,C   3053                        BR BUCK2
45D     62          BUCK1           OUT 2

45E     D4                          SEP CALL
45F,0   C257                        ,A(STOREP)
461,2   8C68                        ,A(TDATA)+#02
463     D5                          SEP RETN
                                    END.
```

15 Aug

MEASUR.SRC.

```
          #0004          CALL=R4
          #0005          RETN=R5
                         ..ADDRESSES
          #02AF          DELAY=#02AF
          #02C1          FDC=#02C1
          #8C22          FMIN=#8C22
          #8C20          FMAX=#8C20
          #8C24          FSTAGE=#8C24
          #8C52          FLAG3=#8C52
          #8C26          FPRECP=#8C26
          #0447          BUCKET=#0445
650461                   ORG #0461 0465
650461 E3             MEASR: SEX PC
660462 65                OUT 5
670463 88 28             ,#88         ..TURN ON HIGH V,FAST CLOCK
680464 D4                SEP CALL     ..DELAY FOR WARM UP
690465 02AF              ,A(DELAY)
6B0467 415C 192C         ,#415C
6D0469 D4                SEP CALL
6E046A 02C1              ,A(FDC)      ..MEASURE COMMON
70046C 88 28             ,#88
71046D 22                ,A.O(FMIN)  ..PLACE RESULT AT FMIN
72046E D4                SEP CALL
73046F 02C1              ,A(FDC)      ..MEASURE V-SYSTEM
750471 89 29             ,#89
760472 20                ,A.O(FMAX)  ..PLACE RESULT AT FMAX
770473 D4                SEP CALL
780474 02C1              ,A(FDC)      ..MEASURE STAGE
7A0476 8A 2A             ,#8A
7B0477 24                ,A.O(FSTAGE) ..STORE RESULT AT FSTAGE
7C0478 F852              LDI A.O(FLAG3) ..POINT TO FLAG3
7E047A A8                PLO R8
7F047B 08                LDN R8       ..GET FLAG3
80047C 3A8569            BNZ MEAS1    ..USR BUCKET IF FLAG3=1
82047E D4                SEP CALL
83047F 02C1              ,A(FDC)      ..MEASURE PRECIP
850481 8B 2B             ,#8B
860482 26                ,A.O(FPRECP) ..STORE RESULT AT FPRECP
870483 308B8C            BR MEAS2     ..BRANCH OVER BUCKET
890485 D4             MEAS1: SEP CALL
8A0486 0445              ,A(BUCKET)   ..MEASURE PRECIP WITH BUCKET
8C0488 D5             MEAS2: SEP RETN ..RETURN TO CALL PROGRAM
                         END

Symbol table

BUCKET    0447     CALL     0004     DELAY    02AF     FDC       02C1
FLAG3     8C52     FMAX     8C20     FMIN     8C22     FPRECP    8C26
```

UTILITY ROUTINES: SOFTWARE.

		ORG#160	
160	F804	LDI A.1(INP/DSP ~~DISPLAY~~)	INPUT/DISPLAY DECIMAL NUMBERS.
	B3	PHI R3	
	F8FE	LDI A.0(INP/DSP ~~DISP~~)	BRANCH TO 04FE
	A3	PLO R3	
	D3	SEP R3	
		ORG#168	
168	F804	LDI A.1(CALIBS)	CALIBRATE STAGE BRANCH TO 04D6
	B3	PHI R3	
	F8D6	LDI A.0(CALIBS)	
	A3	PLO R3	
	D3	SEP R3.	
		ORG#170	
170	F801	LDI A.1(CALIBP)	CALIBRATE PRECIP BRANCH TO 01C0
	B3	PHI R3	
	F8C0	LDI A.0(CALIBP)	
	A3	PLO R3	
	D3	SEP R3.	
178		ORG#178	
	F804	LDI A.1(CMEASR)	MEASURE DATA BRANCH 04C3
	B3	PHI R3	
	F8C3	LDI A.0(CMEASR)	
	A3	PLO R3	
	D3.	SEP R3.	

UTILITY ROUTINES CON'D.

```
                                ORG#180            TEST
0   F801                        LDI A.1(CGXMIT)    TRANSMITTER
    B3                          PHI R3
    F889                        LDI A.0(CGXMIT)
    A3                          PLO R3
    D3 FF                       SEP R3
                                ORG #188
5   F88C       CGXMIT           LDI #8C
    B8                          PHI R8
    F853                        LDI A.0(FLAG4)
    A8                          PLO R8
    F801                        LDI #01
    58                          STR R8
    D4                          SEPCALL
    0114                        ,#0114          CO 04FE
    D4                          SEP CALL
    0965                        ,A(MEASUR)         ,, measure Vcc, Vss.
    D4                          SEP CALL           ,, measure RF out.
    02C1                        ,A(FDC)
    86        (BE)              ,#86
    2E                          ,#2E
    D4                          SEP CALL           ,, measure RF reflected.
    02C1                        ,A(FDC)
    87        (BF)              ,#87
    30                          ,#30
    D4                          SEP CALL           ,, calculate RFOUT.
    03F2                        ,A(CALC)
    2E                          ,A.0(FRFOUT)
    22                          ,A.0(FMIN)         BE
    03E8                        ,1000
    46                          ,A.0(RFOUT)
    5F                          ,A.0(PAD)+16
    5F                          ,A.0(PAD)+16
```

CGXMIT CON'D

```
D4       SEP CALL             ..calc.. RFREFLECTED
03F2     ,A(CALC)
30       ,A.0(FRFIN)
22       ,A.0(FMIN)
03E8     ,1000
49       ,A.0(FREFL)
5F       ,A.0(PAD)+6
5F       ,A.0(PAD)+6
F846     LDI A.0(RFOUT)       ..goto display program
A8       PLO R8    ← E3 65 00   TURN OFF VM
E36500
C004FE   LBR C503
```

CALIBP CON'D

1E3	D4	SEP CALL
E4	03F7	,A(CALC)
E6	22	,A.0(FMIN)
E7	26	,A.0(FREECP)
E8	03E8	,#03E8
EA	66	,A.0(YDATA)
EB	32	,A.0(PREECP1)
EC	2A	,A.0(PMIN)
ED	F82A	LDI A.0(PMIN)
EF	A8	PLO R8
1F0	C00503	LBR LOOP1
1F3.		—

ORG #04C3.

4C3	F88C	CMEASR:	LDI #8C
C5	B8		PHI R8
C6	F859		LDI A.0(FLAG)
C8	A8		PLO R8
C9	F801		LDI #01
CB	58		STR R8
CC	D4		SEP CALL
CD	006F		#006F
CF	F820		LDI A.0(FMAX)
D1	A8		PLO R8
D2	C00503		LBR LOOP1
D5			—

```
                                ORG #0106.
 4D6   D4          CALIBS:      SEP CALL
  D5   0465                     ,A (MEASR)
  D7   D4                       SEP CALL
  D8   03F2                     ,A(CALC)
  DA   22                       ,A.0(FMIN)
  DB   24                       ,A.0(FSTAGE)
  DC   0FA0                     ,#0FA0
  DE   66                       ,A.0(TDATA)
  DF   2C                       ,A.0(STAGE)
  E0   28                       ,A.0(SMIN)
  E1   F828                     LDI A.0(SMIN)
  E3   A8                       PLO R8
  E4   C00503                   LBR LOOP1
  E7

                                ORG #01C0
 01C0  F852        CALIBP       LDI A.0(FLAG3)
  C2   A8                       PLO R8
  C3   F88C                     LDI #8C
  C5   B8                       PHI R8
  C6   08                       LDN R8
  C7   32E0                     BZ
  C9   F861                     LDI A.0(PAD)+7       ..no calibration necessary.
  CB   AF                       PLO RF               display message
  CC   98                       GHI R8
  CD   BF                       PHI RF
  CE   EF                       SEX RF
  CF   F801                     LDI #01
  D1   73                       STXD
  D2   F880                     LDI #80
  D4   73 73 73 73 73 73 5F     STXD,STXD,STXD,STXD,STXD,STXD,STX
  DB   D4          DISPLAY      SEP CALL
  DC   816C                     ,A(LEDD)
  DE   30DB                     BR DISPLAY
  E0   D4                       SEPCALL
  E1   0461                     ,A(MEASR)
```

INSERT /DISPLAY

```
   B3 *
   31 FE
   F8 8C B8 BF        START:  LDI #8C; PHI R8; PHI RF      .. point to RAM
   F8 00 A8                   LDI #00; PLO R8              .. 8C00
   EF                 LOOP1   SEX RF                       .. use RF as stack pointer
   F8 61                      LDI  A.0(PAD)+#07            .. and set up display
   AF                         PLO RF                       .. buffer.
   88                         GLO R8                       .. get unique address
   FA 0F F9 10                ANI #0F; ORI #10             .. and set decimal point
   73                         STXD                         .. set up other displays
   88                         GLO R8
   F6 F6 F6 F6                SHR; SHR; SHR; SHR
   F9 10                      ORI #10
   73                         STXD
   F8 0C 73                   LDI #0C; STXD
   F8 08 73                   LDI #08 ; STXD
   F8 80 73 73 73             LDI #80; STXD; STXD; STXD
   F8 0A 5F                   LDI #0A ; STR RF
   F8 5A              NOKEY.  LDI  A.0(PAD)                .. point RF to Buffer.
   AF                         PLO RF
   D4                         SEP CALL
   81 6C                      ,A(LEDD)
   F                          B3 NOKEY                     .. wait for key to be released
D  F8 01              KEYSCN  LDI #01
F  BA                         PHI RA
0  D4                         SEP CALL
1  07 91                      ,A(READ)
3  F8 61                      LDI  A.0(PAD)+#07
5  AF                         PLO RF
6  9A                         GHI RA
7  32 20                      BZ KEYSCN
9  F6                         SHR
A  32 33                      BZ NOKEY
C  8A                         GLO RA                       .. ENTER KEY PRESSED?
D  F8 12                      XRI #12                      .. TEST IT, BRANCH IF YES.
F  32 53                      BZ ENCODE
1  0F                         LDN RF                       .. SHIFT NEW DIGIT INTO
2  2F                         DEC RF                       .. DISPLAY BUFFER.
3  5F                         STR RF                       .. FIRST MAKE ROOM
```

```
4   1F                         INC RF              ..THEN BRING IT IN
5   8A                         GLO RA
6   F910                       ORI #10             ..remember to set point
8   5F                         STR RF
9   F85A                       LDI A.0(PAD)        ..point to display buffer.
B   AF                         PLO RF
C   D4           WAIT          SEP CALL
D   81 6C                      ,A(LEDD) (DISPLAY struck out)
F   3B 4C                      B3  WAIT            ..IF KEY NOT RELEASED YET, WAIT
1   30 27                      BR  NOKEY.          ..GO AGAIN. FOR MORE DATA.
3   2F
4   4F           ENCODE:       LDA RF              ..ENCODE THE SELECTED
5   FE FE FE FE                SHL;SHL;SHL;SHL     ..ADDRESS INTO ONE
9   52                         STR R2              ..BYTE OF DATA AND
A   0F                         LDN RF              ..STORE IT IN R8.0
B   FA 0F                      ANI #0F             ..R8.0 POINTS TO USER
D   F1                         OR                  ..SELECTED ADDRESS
E   A8                         PLO R8
F   36 5F                      B3 *
1
```

uses R8
RF
LEDD SUBROUTINE
READ SUBROUTINE

```
1     F8 00 A7   LOOPB:   LDI #00, PLO R7         ..Reset flipflop
4     88 AD               GLO R8; PLO RD          ..prepare to load
6     98 BD               GHI R8; PHI RD          ..binary number
8     D4                  SEP CALL                ..
9     C2 4D               ,A(LOAD)                ..Load it,
B     D4                  SEP CALL                ..and convert it
C     C3 0A               ,A(CBD)                 ..to a decimal
E     8C 5C               ,A(PAD)+#02             ..store decimal in
10    06                  ,#06                    ..display buffer
11    D4                  SEPCALL                 ..reformed
12    C2 52               ,A(LOADCON)             ..display buffer to
14    8C 5C               ,A(PAD)+#02             ..desired format.
16    0F                  LDN RF
17    52                  STR R2
18    F8 80               LDI #80
1A    5F                  STR RF
1B    2F                  DEC RF
1C    5F                  STR RF
1D    2F                  DEC RF
1E    02                  LDN R2
1F    5F                  STR RF
80    D4         DISPLY   SEPCALL                 ..DISPLAY CONTENTS
81    81 6C               ,A(LEDD)                ..OF DISPLAY BUFFER.
83    F8 01      KEYSCN   LDI #01
85    BA                  PHI RA
86    D4                  SEP CALL                ..scan the keys
87    04 91               ,A(READ)
89    9A                  GHI RA
8A    32 83               BZ KEYSCN               ..bad read, try again
8C    F6                  SHR
8D    32 80               BZ DISPLY.              ..no key pressed, branch
8F    8A                  GLO RA
90    FB 12               XRI #12
92    32 D8               BZ INSERT               .."INC" WAS PRESSED, BRANCH
```

```
594     8A                                  GLO RA
595     FB 10                               XRI #10              ..was ↔ pressed
597     3A A3                      ┌─────── BNZ NOF              .. NO, BRANCH
599     87                         │        GLO R7               ..yes it was flipflop
59A     3A 9E                      │  ┌──── BNZ F1
59C     17                         │  │     INC R7               ..change 0->1
59D     38                         │  │    ┌SKP
59E     27                         │  F1:  │ DEC R7              ..or change 1->0
59F     87                         │       └ GLO R7
5A0     CA 04 AD   CLEAR <─────────┼──────── LBNZ CLEAR          ..if now 1 clean out buffer
5A3     87                         └NOF:     GLO R7              ..if zero, data at address
5A4     32 5F      LOOPB <─────────────────── BZ LOOP B-#02       ..cannot be changed, branch
5A6     8A                                   GLO RA
5A7     FB 0B                                XRI #0B             ..was B pressed
5A9     3A AF                       ┌─────── BNZ NOB             ..if no, branch
5AB     8A                          │        GLO RA              ..store B in sign
5AC     5F                          │        STR RF              .position of display
5AD     30 E1                ┌──────┼─────── BR F6               ..buffer, branch
5AF     8A                   │     NOB       GLO RA
5B0     FB 0D                │               XRI #0D             ..was D pressed
5B2     3A B8                │      ┌─────── BNZ NOD             ..if no, branch
5B4     8A                   │      │        GLO RA              ..store D in sign
5B5     5F                   │      │        STR RF              .position of display
5B6     30 E1                ├──────┼─────── BR F6               ..buffer, branch
5B8     F8 04                │     NOD       LDI #04
5BA     AD                   │               PLO RD
5BB     F8 5E                │               LDI A.0(PAD)+#04
5BD     AF                   │               PLO RF              ..shift display
5BE     0F                   │    SHIFT:     LDN RF              ..digits one place to
5BF     2F                   │     │         DEC RF              ..the left.
5C0     5F                   │     │         STR RF
5C1     2D                   │     │         DEC RD
5C2     8D                   │     │         GLO RD
5C3     32 C9                │     │   ┌──── BZ
5C5     1F 1F                │     │   │     INC RF; INC RF
5C7     30 BE                │     └───┼──── BR SHIFT       ORI #10
5C9     1F 8A F9 10 5F       │         └──── INC RF; GLO RA, STR RF ..put new digit in proper place.
5CE     F8 5D                │     F5        LDI A.0 (PAD)+#03  ..
5D0     AF                   V               PLO RF
                             F6
```

```
5D1    F85A        F6:     LDI A.0(PAD)
5D3    AF                  PLO RF
5D4    D4          WAIT:   SEP CALL
5D5    81 6C               ,A(LEDD)
5D7    36 D4               B3 WAIT
5D9    30 80               BR DISPLY

5DB    F85A        INSERT  LDI A.0(PAD)          .. reformat display buffer
5DD    AF                  PLO RF                .. to BCD format
5DE    0F                  LDN RF
5DF    1F                  INC RF
5E0    1F                  INC RF
5E1    5F                  STR RF
5E2    D4                  SEP CALL
5E3    C2 9F               ,A(CDB)               .. convert decimal to
5E5    8C 5C               ,A(PAD)+#02           .. binary
5E7    06                  ,#06
5E8    98 BD               GHI R8; PHI RD
5EA    88 AD               GLO R8 ; PLO RD
5EC    D4                  SEP CALL              .. store result in desired
5ED    C2 58               ,A(STORE)             .. address
5EF    18                  INC R8                .. take next address
5F0    18                  INC R8
5F1    36 F1               B3 *                  .. wait for key to be released
5F3    30 03               BR LOOP1              .. start over again

04AD   F861        CLEAR:  LDI A.0(PAD)+#07
04AF   AF                  PLO RF
04B0   EF                  SEX RF
04B1   F810                LDI#10
04B3   73 73 73 73 73      STXD, STXD, STXD, STXD, STXD
04B8   F8 80               LDI #80
04BA   73 73               STXD, STXD
04BC   F8 0B               LDI #0B
04BE   73                  STXD
04BF   C0 05D1             LBR F6
```